The Wabash River Ecosystem II
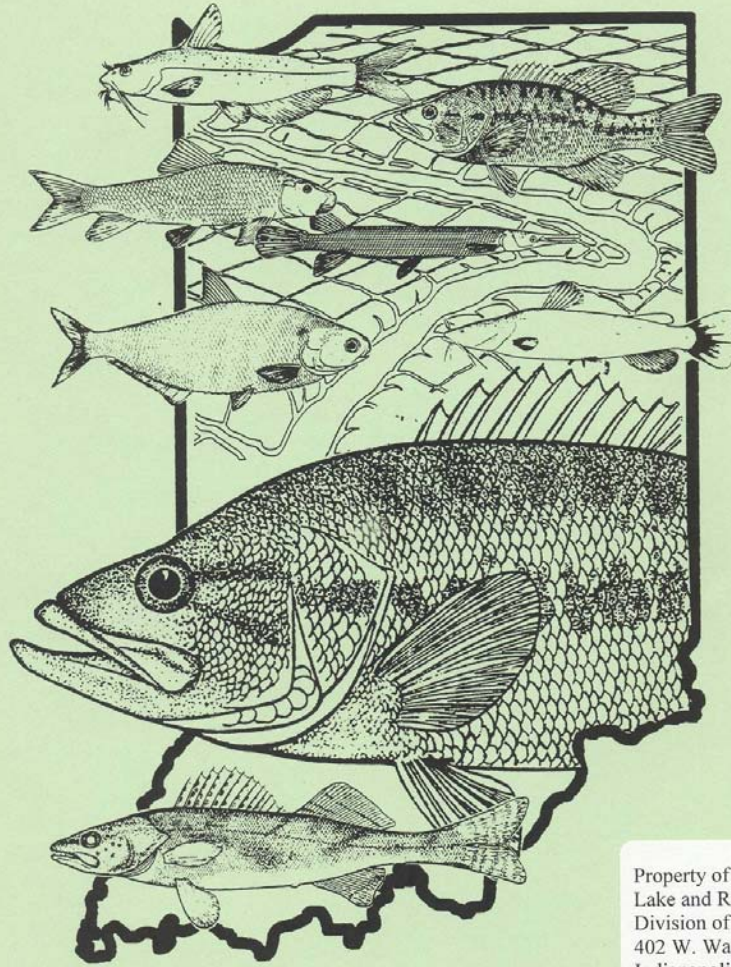
A Report for

PSI-Energy
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and
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by

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DEPAUW
UNIVERSITY

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ACKNOWLEDGEMENTS

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The catch data on which much of the report is based is too extensive to include in Appendix Tables as was done with previous reports. Anyone interested in securing summaries of the catch data should request it from the author. Several forms of output are capable of being generated and placed as ASCI files on computer diskette or sent electronically through INTERNET.

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ABSTRACT

The fish community of the Wabash River has been studied since 1967, focusing initially on thermal effects near the Wabash River electric generating station (EGS) north of Terre Haute, Indiana and the preoperational Cayuga EGS near Cayuga, Indiana. In 1973 the studies were extended upriver and downriver because of the realization that heat was but one of many environmental influences on the river's biota.

The Wabash River fish community includes a great diversity of warm-water species distributed widely throughout the Mississippi River system. Most species have been present since presettlement times. The most common large species are gizzard shad (*Dorosoma cepedianum*), carp (*Cyprinus carpio*), northern river carpsucker (*Carpiodes carpio*) together with a large variety of catostomids (*Moxostoma sp., Ictiobus sp.,* and *Cycleptus elongatus*), centrarchids (*Micropterus sp., Pomoxis sp., and Lepomis sp.*), and gar (*Lepisosteus sp.*). Freshwater drum (*Aplodinotus grunniens*), white bass (*Morone chrysops*), channel catfish (*Ictalurus punctatus*) and flathead catfish (*Pylodictis olivaris*) are also important members of the fish community. Less common, but interesting, species include goldeye and mooneye (*Hiodon sp.*), skipjack herring (*Alosa chrysochloris*), bowfin (*Amia calva*), sauger (*Stizostedion canadense*), American eel (*Anguilla rostrata*), and shovelnose sturgeon *Scaphirhynchus platorynchus*). The smaller species include a diversity of minnows (*Notropis sp., Macrhybopsis sp.,* and *Pimephales sp.*), madtoms (*Noturus sp.*), and darters (*Percina sp.* and *Etheostoma sp.*)

A variety of collecting methods were examined during the early years of study. D.C. electrofishing proved to be most effective method of collecting the greatest variety of species in the Wabash River. During summers when river discharge permitted, fish were collected 3 times each summer from 63 stations scattered through 250 km (160 mi) of river between Delphi, Indiana and Merom, Indiana since 1973. Each station was 0.5 km long and sited in relatively fast-water with good cover and depths of 1.5 m. or less. The catch data were further combined to represent the fish communities in 12 Reaches varying in length.

A good fish community is one with both an abundance of individuals and a high diversity of species. After investigating various community parameters, a Composite Index of Well-Being (Iwb) was formulated to quantitatively represent the fish communities from electrofishing catches (Gammon 1976, 1980):

$$\text{Iwb} = 0.5 \ln N + 0.5 \ln W + \text{Div.}_{\text{no.}} + \text{Div.}_{\text{wt.}}$$

where N = number of fish captured per km
W = weight in kg of fish captured per km
$\text{Div.}_{\text{no.}}$ = Shannon diversity based on numbers
$\text{Div.}_{\text{wt.}}$ = Shannon diversity based on weight

High Iwb values corresponded well with other kinds of community parameters such as high species richness and were characteristic of excellent fish communities. Low Iwb values coincided with low community values and represented poor fish communities.

The long-term studies of the Wabash River have permitted us to:

(a) document recent overall improvements in the fish communities,

(b) identify problem sections of the river,

(c) evaluate ecological changes associated with operational modifications by industry,

(d) discriminate between natural and man-induced effects, and

(e) clarify ecological interactions among the major biotic components of the ecosystem.

The overall fish community in the Wabash River improved markedly after 1983. The upper five reaches improved from poor-fair to fair and good while the lower three reaches improved from Poor to Fair. Most species populations, except for carp and gizzard shad, improved noticeably. Some populations (eg. blue sucker, mooneye, and spotted bass) expanded into previously unoccupied areas of the river. Many other species of fish also increased, especially in the upper portion of the study segment. Species which reproduce and live in the mainstem increased greatly in density (eg. channel catfish, flathead catfish, sauger, spotted bass, mooneye, goldeye, northern river carpsucker, blue sucker, and drum). Species which enter the mainstem from offstream reservoirs also increased significantly, eg. white bass and walleye. Species entering from clean tributaries also increased (eg. smallmouth bass and longear sunfish). At the same time, the carp population remained stable. The gizzard shad population declined because the piscivore population quadrupled and cropped off young-of-the-year for several years.

Despite greater numbers of young recruits for many species populations, there was also an increase in the average size.

This recovery probably resulted from a combination of long-term, 50% reduction in BOD loading through improved point-source waste treatment and low-flow summers in 1983, 1988, and 1991 which facilitated good reproduction and survival through the first year. Point source pollution from the Lafayette\West Lafayette and Terre Haute areas has been reduced in recent years with demonstrable improvement in local fish communities.

A 25% reduction in agricultural loadings to the river during the 1983 Payment-in-Kind (PIK) program may have contributed. No-till agriculture is rapidly being adopted throughout the basin and may be an important positive force in the future.

Two recent periods of dry summer weather (1988 and 1991) probably reduced nonpoint-source pollution from strip-mining areas as well as agricultural fields and promoted good reproduction. Prolonged midsummer periods of high water not only destroyed reproduction in 1992 and 1993, but also devastated other year classes and, therefore, populations of most larger species to lower levels than ever before observed. However, the fish populations appear to be poised for another positive surge because of the benevolent flows during the summer of 1994.

The improvement in water quality and the biotic communities indicates that the Wabash River ecosystem is amenable to pollution abatement efforts and could become a valuable recreational asset. Continued improvement may depend partly

upon limiting nutrient delivery and reducing algal densities which strongly and negative affect dissolved oxygen concentrations and turbidity during the summer. The phytoplankton community should be examined much more closely since it appears to be the most single important biotic determinant of water quality in the river because of its effect on turbidity and dissolved oxygen during the summer. Nonpoint-source pollution from active and derelict strip-mines is slowly being addressed and may ultimately benefit the Wabash River south of the Big Vermilion River.

The riparian corridor of the Wabash River mainstem and its tributaries has become critically narrow, and even nonexistent, in far too many places. In 1994 more than 11% of the river corridor consisted of bare banks or banks supporting only 1-2 trees between water's edge and the flanking corn and soybean fields. Significant changes were noted during the 1970s when agriculture was expanded. Willow groves have invaded many formerly denuded areas during the last decade, but accelerated lateral erosion could well occur with depressive effects on the fish community. Efforts should be made to determine desirable and realistic widths of river corridors consisting of permanent vegetation and programs should be instituted to restore them where needed.

Clams (Mussels) are the most commercially important biotic component of the Wabash River ecosystem. Depletion of the clam population because of over-harvesting during drought years forced the state to close the harvesting of clams indefinitely. The impending arrival of zebra mussels (*Dreissena polymorpha*) to the Wabash River ecosystem could lead to further declines in native mussels, although it remains to be seen if this species can achieve the high population densities in turbid rivers such as the Wabash as they have in the Great Lakes.

HISTORIC INFLUENCES ON THE WABASH RIVER ECOSYSTEM

The pre-glacial Wabash River ran through a large valley extending from about Lafayette to its mouth and dates back to the Devonian Period more than 350 million years ago. As part of the ancient Mississippi River system, its aquatic fauna has evolved over an immense period of time. This ancient valley, however, is buried in sand and gravel to a depth of 60 or 70 feet, a legacy of the Illinoian and Wisconsin glaciers of 18,000 to 20,000 years ago. During the Illinoian ice sheet, virtually the entire Wabash River valley was covered by ice.

Prior to this time, geological and natural biological processes influenced the Wabash River and its valley, but after the glacial retreat a new ecological element - Man - entered the valley.

The Indian Era: 8,000 BC - 1780

Sometime prior to this, perhaps 18,000 to 28,000 years ago, the first humans entered the North American continent from Asia, probably during an interglacial period (Bray, Swanson, and Farrington 1973). From what is now western Alaska, they may have proceeded eastward and southward, perhaps between the Coast Range and the Rocky Mountains and almost certainly east of the Rockies into the upper Saskatchewan River valley. They left behind evidence of their presence in the form of bone tools and the bones of elephants and camels which they hunted and ate, but evidence is scattered and meager.

The glaciers reached their most southerly extent by 20,000 to 18,000 years ago and pushed these early "colonists" southward into what is now western U.S., an area which was unglaciated except at higher elevations. From 18,000 to 9,000 years ago, as the glaciers retreated to the north, these **Clovis** people spread not only further southward, but also eastward into present midwestern U.S. In what is now southern Indiana, they may have killed deer and remnants of caribou herds and grew in numbers and diversification.

From 10,000 to 8,000 years ago there was a continent-wide change in prehistoric cultures which coincided with a rise in temperature. Perhaps this was necessitated by the spread of prairies eastward and by oak forests northward. During this period native camps and villages shifted from upland locations to river valleys where freshwater shellfish were gathered, whitetail deer hunted, and berries, nuts, and roots gathered. With this increased skill in the utilization of natural resources, specialized tools and distinctive regional cultures developed. An overall summary of supposed events follows.

Southern Indiana lies in the northern part of the **Indian Knoll** culture, part of the **Archaic** culture which prevailed from 10,000 to 3,000 years ago and extended throughout southeast North America from Florida to West Virginia west to Louisiana and Arkansas. The northern part of the **Archaic** culture, the **Laurentian** culture, extended from Wisconsin to Laborador and may have included extreme northern Indiana. Extensive trading was carried on, as evidenced by the appearance of artifacts such as copper tools from the upper Great Lakes in burial sites in the south, as well as milling stones, atlatls (spear throwers), awls, and baskets.

The river floodplain provided soil enriched each year by floods. Agriculture began to be practiced about 3,000 years ago, and by 300 A.D., most river valleys

throughout North America, including the lower Wabash River valley, had farming settlements, This included the **Adena-Hopewell** culture of the Ohio and Illinois River valleys, a culture which constructed many large and small rounded burial mounds, used tobacco and copper ornaments, and built wood and wattle houses. The **Adena** people reached a rather high population density and formed large settled areas consisting of scattered small villages of two to five huts. Intertribal trading was extensive. Two main features of the **Adena** culture were cremation of the dead and the entombment of their remains in log or clay-lined chambers covered by rounded mounds (Hyde, 1962).

From 200 B.C. to 500 A.D. the **Hopewell** culture appeared in the Ohio Valley borrowing from the **Adena** and elaborating mound-building practices to their cultural zenith and introducing pottery. By 400 to 500 A.D. the **Hopewell** arts and crafts declined for unknown reasons. The large burial chambers were no longer built and lowland mounds were abandoned for fortified hilltops.

From 700 to 1700 the **Mississippi** culture expanded northward from its southern nucleus, bringing with it flat-topped mounds bearing temples, a new strain of corn, flint hoes, and elaborate fortifications which protected fields and homes from warring invaders. This culture probably reached the lower Wabash River valley near the end of its development around 1400 to 1500. A great center and fortress was constructed east of the Wabash River and north of the Ohio River near the present Evansville (Hyde 1962, pg. 149). This new culture was transitory, however, and declined shortly thereafter everywhere. Early Spanish explorers arrived in the southeast just in time to briefly describe the last of the temples.

From the foregoing summary it is evident that the Wabash River valley has been occupied by humans for thousands of years. For at least 10,000 years the rich land and water resources have sustained first hunting and gathering **Archaic** cultures and then a sequence of agricultural cultures dating from about 3,000 years ago to the time Europeans first entered the area.

Events during the 1500s and 1600s are confused and poorly understood. In 1608 Samuel de Champlain, following the route traveled in 1535-1543 by Jacque Cartier up the St. Lawrence River, built a fort at Quebec and ushered in the era of trading, which included guns as well as fur and other items. The **Iroquois** had been raiding into the Ohio Valley before the year 1600, but after obtaining European weapons, particularly firearms, they eliminated many neighboring tribes and drove survivors westward and southward. Hyde (1962, pg. 166) suggests that the **Iroquois** had driven most other Indian tribes out of the Ohio River valley by the time Marquette and Joliet reached the Mississippi River in 1673 and **"from 1670 on their war parties continued to rove in the Ohio Valley, through lands desolate and silent, stripped of all inhabitants by Iroquois attacks."** During the next decade or so the **Iroquois** continued to drive other tribes westward even beyond the Mississippi River, but never themselves settled in the Ohio River valley.

At the close of the 17th century tribes from the north began to recolonize the Ohio River valley. **Delawares** and **Shawnees** returned to the upper Ohio River Valley and
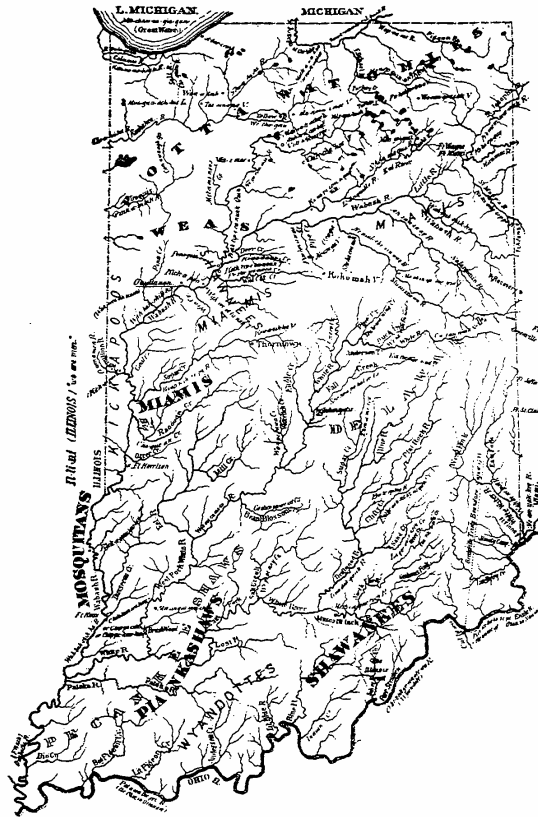
Figure 1: Locations of Indian tribes and villages 1750 - 1850. (After State Geological Report, 1882)

the Algonquian tribes of Wisconsin, the **Miamis**, **Mascoutens**, **Weas**, and **Pianka-shaws**, moved into the Wabash River Valley (Figure 1). The **Miamis** established themselves in the upper Wabash River valley where their main village was Kekionga, the present Fort Wayne. The **Wea** moved to the Wabash River near present West Lafayette and established Ouiatenon. The **Pianka-**

shaws had a village at the mouth of the Big Vermillion River, where they were joined in 1750 by a branch of the **Kickapoos**, and another village called Chippekawkay near present Vincennes. Other tribes occupied various tributaries of the Wabash River. Throughout this period and into the 1700's the French and English expanded their trading activities. The French built forts and

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Throughout this period and into the 1700's the French and English expanded their trading activities. The French built forts and a chain of trading posts to connect settlements and military posts in Louisiana with fur trading centers in Chicago, Detroit, and Canada. They built Fort de Chartres near Kaskaskia in Illinois and sent Frenchman, the *coureurs de bois*, to establish themselves among the Indians on the Wabash. When Francois-Marie Bissot founded a military and trading post at Vincennes in 1732-33 (McCord 1970) **"the Wabash (was) composed of five nations who compose four villages of which the least has sixty men carrying arms, and all of them could furnish from six to seven hundred men if it were necessary to**

assemble them.."

During the middle 1700's the French and English vied for control over native tribes, but not until 1765 was the issue finally settled in favor of the British.   In   1779 George Rogers Clark defeated the British at Vincennes and made it the first American seat of government northwest of the Ohio River.   Originally called the County of Illinois, under the government of Virginia, it was known later as the Northwest Territory and included all of what is now Ohio, Indiana, Illinois, Michigan, and Wisconsin. During the next few decades the influence of white settlers on the Wabash Valley ecosystem would increase dramatically.

Figure 2: The Wabash River near Logansport, Indiana, 1848. George Winter, *Scene on the Wabash*, oil on canvas, 29 x 36 inches. Photo courtesy of the Gerald Peters Gallery, Sante Fe, New Mexico

The Settlement Era 1780 - 1880

In 1800 the white population of Indiana was only 5,641 (Melish, 1822 in Lindley, 1916), most in scattered small communities near rivers. In 1810 it was 24,520; in 1815, 68,784; and in 1820 it was 147,178 including whites, free blacks, and slaves, but not counting Indians. These early residents found a ready market for their surplus agricultural products in New Orleans and floated them on flatboats down the Wabash and White Rivers to the Ohio and then on to New Orleans during the spring floods.

However, by 1827 the New Orleans market became saturated and ways were sought to transport the goods to and from the eastern markets (Esarey, 1912). Steamboats were already plying Wabash waters as far upriver as Terre Haute and even to Ouiatanon south of Lafayette.

Until 1815 few written accounts of the rivers and streams are available, although French fur-traders had lived in harmony with the Indians for at least a century before. In 1792 Heckewelder (McCord 1970, pg. 35) wrote of the river near Vincennes ..."the **Wabash as clear as the Monocasy, full of fish, . . "**

Indian opposition to settlers moving north of the Ohio River had been dealt with by 1815 and settlers entered in increasing numbers because of the rich agricultural lands. Caleb Lownes in a letter to Oliver Wolcott (Sec. Treas. under Presidents Washington and Adams) wrote in 1815 (McCord, 1970): ..."**The first rate lands lie on the Wabash all the way to the lakes on the most beautiful stream in my recollection--it is about 250 yards wide at this place (Vincennes) and preserves its width very**

nearly for 400 miles...It is a beautiful and valuable stream--the water generally perfectly clear and transparent--exhibiting a clean gravelly bottom--It abounds with fish of various kinds--Bass-Pickerel, Pike-Perch-Catfish &c. The Catfish are of every size up to 122 1/2 lb. one of this size was caught (at Fort Harrison 80 miles above this)--The perch (probably smallmouth bass) are from 12 to 20 in length-this appears to be dealing in the marvelous but it is nevertheless correct--a large White fish about 2 1/2 feet long with very little bone was yesterday caught by a gentlemen on a party said to be excellent."

Most early accounts focused on the fertility of the land and the rivers were examined mostly as potential sites for mills and water for floating boats loaded with future produce. There was no recognition that blocking small tributaries of the Wabash River might have some effect on the reproductive success of some species of fish. Enoch Honeywell wrote in his diary (McCord, 1970): **"Apr (May) 1816. saw Ft. Harrison. There is about 12 families living in and near the fort and 10 to 12 more at 6 miles distance southeast 2 at 8 miles south, which are all of 25 miles. The river here is 50 to 60 rods wide, very deep, clayey banks, always navigable for keel-boats except over the grand rapid below Vincennes in low water. In freshes it inundates its banks very bad; on the west side the river here it floods about a mile, but the soil being light the water soon drains off or soaks in."**

By far the finest early account of the area is that of David Thomas (1819). Had his interest in rivers and lakes been half that of his interest in vegetation and wild life, we would have a very detailed, clear account of aquatic life, indeed. Nevertheless, some
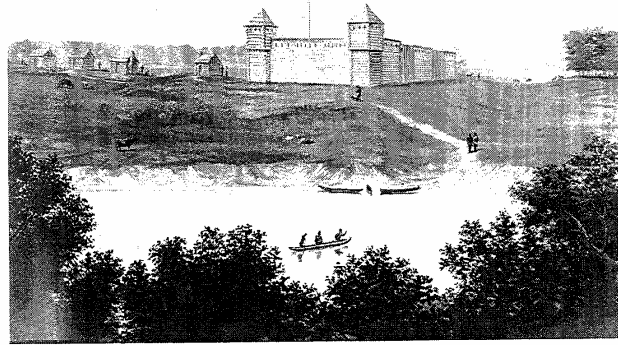
Figure 3: Fort Harrison located on the east bank of the Wabash River near Lost Creek in Vigo County.
(Vigo County Historical Museum, Terre Haute, Indiana)

illuminating comments about the Wabash River as far north as Otter Creek were made.

"The water of the Wabash forms a good lather with soap, At Pittsburgh, for washing, the river water was good, but it becomes harder in its descent. At Cincinnati an increase of lime was evident; and near the mouth of the Wabash, the water of the Ohio was hard"...

"The Wabash has a gentle current, except at the Rapids, twenty-three miles below Vincennes"...

"The Wabash is four hundred yards wide at its mouth, three hundred at Vincennes,

and two hundred at Fort Harrison. It is fordable in many places."

"Whenever a high piece of land appears on one side of the River, the opposite shore is low and sunken; and from Raccoon Creek, fifteen miles above Fort Harrison to the mouth of the river, I believe there is no exception to this remark."

"There is one inconvenience attending this country, exclusive of the overflowing of the Wabash. all its tributary streams after a heavy shower of rain, rise above the banks; and overflow the low land adjoining, which on all, is of considerable extent. In time of high water, it is one of the most difficult

countries to travel through, I ever saw. I have known it for more than four weeks at one time, that no person could get away from Union Prairie without swimming his horse, or going in a boat."

"The Wabash abounds with fish of many kinds; which, in the months of April, May and June, may be readily caught with the hook and line."

"The Gar or Bill fish is more than two feet in length. It is quite slim. The bill is about six inches long, tapering to a point. Its scales are very close, thick, and hard."

"The strength of this fish is great. In a small creek which flows into the Wabash, I discovered a considerable number, and caught several in my hands; but was absolutely unable to hold one."

"There are three kinds of Cat-fish: the Mississippi cat, the mud cat, and the bull head. Some of the first have weighed one hundred and twenty pounds. The mud cat is covered with clouded spots and is a very homely fish. The head is very wide and flat. Some have weighed one hundred pounds."

"The real sturgeon is found in the Wabash though the size is not large. These have been taken from twenty to sixty pounds weight."

"The shovel fish or flat nose is another species of sturgeon. It weighs about twenty pounds."

"The pond pike is taken in ponds from one to three feet long, but very slim. It is an excellent fish." (Northern pike)

"The river pike is large and highly esteemed, but scarce." (Muskellunge)

"The drum or white perch weighs from one to thirty pounds. It is shaped like the sunfish."

"The black perch or bass is excellent, and weighs from one to seven pounds." (Smallmouth bass)

"The streaked bass is scarce." (White bass)

"The Buffalo fish is of the sucker kind, and very common. Weight from two to thirty pounds."

"The rock Mullett is sometimes seen three feet long. It is slim and weighs from 10 to 15 pounds." (Smallmouth buffalo?)

"The red horse is also of the sucker kind. It is large and bony, weighing from five to fifteen pounds."

"The Jack pike or pickerel is an excellent fish, and weighs from six to twenty pounds." (Walleye pike)

"The eel is frequently taken in the Wabash, and weighs from one to three pounds. I was told that no fish was found in these waters of a good quality for pickling; and the facts, that mackerel are brought over the mountains from Philadelphia, and white fish from Detroit, tend to confirm that statement."

"The fresh water clam or muscle is so plenty, as to be gathered and burnt for lime. Twenty years ago, I am told, no other kind of lime was procured."

Figure 4: Darwin Ferry located between Merom, IN and Terre Haute, IN. circa 1850. (Vigo County Historical Museum, Terre Haute, Indiana)

Figure 5: Darwin Ferry today with Darwin, IL across the river.

"Craw fish, which resembles the lobster, is very common in the low lands of this country. It is a size larger than the common crab. It works in the ground, and throws up heaps of earth about six inches high, and hollow within. These little mounds are very numerous, and the surface of the ground resembles a honey comb."

Thomas also noted the frequency of sick people offered some recommendations to the traveler and new settler, among which: "Let no temptation prevail on the emigrant to go fishing in warm weather. Of the smell of the shores I have spoken. To be wet is imprudent; and to be exposed to the chilling damps of the night, greatly increases the danger. But fresh fish are unwholesome, except for a slight change of diet. We know of no new settlement that has been healthy, where the inhabitants live chiefly on fresh fish. If, however, fish must be eaten, buy them; any price is cheaper than health; and if fishing must be done, do it in cloudy weather; but at night be comfortably sheltered."

Figure 6: View of the lower Wabash River, by the noted Swiss painter Karl Bodmer, who accompanied Maximilian on his visit to New Harmony.

The great clarity of water was remarked upon by more than one observer. Mrs. Lydia Bacon (McCord, 1970) wrote of 1811 Vincennes "the local situation of the place is very pleasant, lying on a clean stream of Water which affords them a variety of fish & facilitates their intercourse with the Neighbouring States & Territories."

"It was in the month of April (1825) when I first saw the Wabash River...Schools of fishes--salmon, bass, redhorse, and pike--swam close along the shore, catching at the blossoms of the red-bud and plum that floated on the surface of the water, which was so clear that myriads of the finny tribe could be seen darting hither and thither amidst the limpid element, turning up their silvery sides as they sped out into deeper water." (Cox, 1860).

Hugh McCulloch (McCord 1970, pg.147) visited the Wabash River at Logansport in late May, 1833 and wrote ". . I followed an Indian trail that led along the banks of the Wabash, which had not then been deprived of any of their natural beauty by either freshets or the axe of the settler. The river was bank-full. Its water was clear, and as it sparkled in the sunlight or reflected the branches of the trees which hung over it, I thought it was more beautiful than even the Ohio..."

Fish were plentiful and easy to obtain at this time. Rafinesque (1820) stated "Fishes are very abundant in the Ohio, and are taken sometimes by the thousands with the seines.." "The most usual manners of catching fish...are, with seines or harpoons at night and in shallow water, with boats carrying a light, or with the hooks and line, and even with baskets."

Rafinesque (1836), the first scientist to study the life of the Ohio River and its tributaries, descended the River from Pittsburg during the summer of 1818 where he first "began to study the fishes which we caught or bought, making drawings, &c". Most of his direct observations were made on Ohio River species and there is no indication that he himself studied fish specimens from the Wabash River. He has been described as brilliant and eccentric with a roving character of mind which was to lead him into mental vagabondage, wandering at will over the entire field of books and nature. Certainly he was the consumate "splitter", finding a multiplicity of species where only one, in actuality, existed. Nevertheless, prior to his studies only about 12 resident species had been properly named and described. By 1819 he had described about 100 species.

One of the people to which Rafinesque's 1820 book was dedicated was Charles Alexander Lesueur, a naturalist who had first described species of fish from Lakes Erie and Ontario. Lesueur arrived in New Harmony on the lower Wabash in January 1826 in the company of many other noted scholars including Thomas Say, the so-called "father of American Zoology". Here he worked for 10 years, intending to complete a work on the fishes of North America. He was an excellent artist and sketched extensively in his travels up and down the entire Mississippi River, but he was a poor writer and never completed his intended work.

Most of Lesueur's limited writings and extensive sketches returned with him to France in 1837 after the death of Say. In 1845 he became the first curator of the Museum d'Histoire Naturelle at Le Havre

Figure 7: Charles-Alexandre Lesueur drawn by Swiss artist Karl Bodmer, who accompanied Maximilian.

(Pitzer, 1989). Some of his 1200 sketches have been published in three volumes by Bonnemains (1984).

Thomas Say drew and described many species of insects and molluscs and completed several excellent publications at New Harmony before his death and burial there.

Species of fish which Rafinesque regarded as abundant or common in the Ohio River included: drum, the three species of black bass, bigmouth buffalo, shovelnose sturgeon, channel catfish, yellow bullhead, goldeye, mooneye, emerald shiner, golden shiner, log perch, greenside darter, and fantail darter. Hook and line fishing was too slow for the settler and, in addition to seining, spearing and gigging were popular in clear water streams containing an abundance of fish.

On the smaller Wabash tributaries still other means were employed: "At John Stitt's mill below town (Crawfordsville), on Sugar river, there is a fish-trap, and in one night we caught nine hundred fish, the first Spring we were in the country (1825), most of them pike, salmon, bass, and perch. Some of the largest pike and salmon (Walleye) measured from two to four feet in length, and weighed from twelve to twenty-five pounds." (Cox, 1860).

Dunn (1910) records the abundance of fish in the White River according to early residents of Indianapolis as follows: "George W. Pitts commented "There was no end of fish in the streams in those days. I went up to McCormick's dam (just above the Country Club) four miles above town on the river one day and sat down at a chute that had broken out and where fish were running through. There were wagon loads of fish, and I threw out with my hand eighty-seven bass, ranging in size from one pound up to five."

"Amos Hanway says there were 'bass, salmon (walleye and/or sauger), redhorse, ordinary suckers, quillbacks, or as they were sometimes called spearbacks, perch, pike, catfish, etc. The biggest salmon I ever caught weighed sixteen pounds. I once caught a pike that measured four feet and two inches (Muskellunge); at another time a gar-fish that measured over three feet, and a blue catfish that weighed sixteen and a quarter pounds. The finest rock bass (largemouth bass) I ever took was one which weighed eight and a quarter pounds, and that was near Waverly; while the biggest river bass (smallmouth bass) I ever lifted from the water weighed six and one-fourth pounds.'" He went on to say that once in Morgan County, above the Cox dam, when

Sam "at one haul seined twelve barrels of fish, and there were thirty fish that averaged, undressed, ten pounds each. They were mostly bass and salmon, but there were also large redhorse, white perch, quillbacks and ordinary suckers."

The importance of an abundance of excellent fish is stressed. Flint (1826, in Lindley, 1916): "The streams, and especially those that communicate with Lake Michigan, are abundant in fish of the best qualities. The number and excellence of the fish, and the ease, with which they are taken, are circumstances of real importance and advantage to the first settlers, and help to sustain them, until they are enabled to subsist by the vails of cultivation."

Maximilian, Prince of Wied (1843) overwintered from Oct. 19, 1832 to March 16, 1833 at New Harmony, which at that time had a population of 600. "The Wabash, a fine river, as broad as the Moselle, winds between banks which are now cultivated, but were lately covered with thick forests." He wrote about the large size and diversity of trees, and described the understory. He was familiar with many birds and other animals. At that time bison, elk, bear, and beaver were "now entirely extirpated." although in the first decade of the 1800's there were many bear & wolves, and small numbers of elk and beaver. "The Virginia deer is still pretty numerous, but is daily becoming more scarce." "The wolf is still common, . ." Grey and red fox, racoon, opossum, groundhog, muskrat squirrel, polecat, otter, & mink were all common and rabbits and pine martin were sometimes seen.

Snapping, softshell, and other emys "are numerous" "The proteus (Menobranchus lateralis, Harl.) of the Ohio and of the great Canadian lakes, is found in the Wabash." This may have been either hellbender, mud puppy or both. "There are many kinds of fish in the Wabash, on the whole the same as in the Ohio and the Mississippi. 100 pound catfish, several species of sturgeon and pikes, the horn-fish, the buffalo, . . a large fish resembling the carp, &c., paddlefish" "At places where the flat boats, laden with maize, land, the fish collect and assemble in great numbers, and fall an easy prey to the fisherman."

He spent a winter which was unusually mild and dry and, on a trip with Le Sueur, commented "The water of the river is clear and dark green, and the bottom, which is plainly seen, is covered with bivalve shells (Unio), as well as with several kinds of snails."

"Indians were reported to have lived around Harmony until 1810, but in the year preceding the battle of Tippecanoe they all removed, and did not return." He cryptically says that Indians were "now totally extirpated and expelled from Indiana, and the country enjoys the advantage of being peopled by the backwoodsman."

Of the local residents Maximillian says they are ". .called backwoodsmen because they live in the remote forests. . . a robust, rough race of men, of English-Irish origin." "They dwell very isolated, scattered in the forests, and seldom come to town, only when business calls them."

Great changes were to occur between 1830 and 1845, as Cox (1860) poignantly writes: "I can well recollect when we used to wonder if the youngest of us would ever live to see the day when the whole of the Wea plain would be purchased and cultivated;

and our neighbors on the Shawnee, Wild Cat, and Nine Mile prairies were as shortsighted as we were, for they talked of the everlasting range they would have for their cattle and horses on those prairies--of the wild game and fish that would be sufficient for them, and their sons, and their sons' sons. But those prairies, for more than fifteen years past, have been like so many cultivated gardens, and as for venison, wild turkies and fish, they are now mostly brought from the Kankakee and the lakes."

George Winter, one of the first professional artists to live and work in Indiana at Logansport, recorded his observations in diaries and letters. In 1841 he writes: "The sprightly Wabash was low (July) and its rocky bed was ocassionally visible, yet it flowed wildly on. The river is a clear and rushing stream, dotted by small islands-which threw their images upon the glassy surface. It was a mixed scene that presented itself to the eye, combining the wild with the partial markings of civilization: on the southern side of the Wabash is the great Miami Reservation, known for its unsurpassed excellence of soil and valuable timber. It is a noble but Fated forest, and the sound of the axe had already reverberated in its shady recesses."

A few years later Winter commented "Now A.D. 1845 we witness . . . the effects of the partial clearing up the country . . . has had a striking effect upon the affluents of the Wabash-the beautiful Islands . . . are beginning to wash away under the influence of the greater volume of water that fills the banks and increased rapidity of the current of the river."

The changes, of course, came about as the direct and indirect result of a rapidly increasing population and establishment of extensive agriculture which led, in turn, to the exportation of surplus agricultural goods. Navigable waters throughout the state were clearly needed, but the physical clearing of the land itself acted against this need in many of the smaller streams.

"Unquestionably White River is not so easily navigable now as it was ninety years ago, though probably as much water passes out through its channel in the course of a year as there did then. The flow is not so steady because of the clearing of the land and improved drainage make the surface water pass off more rapidly. And this has increased the obstructions in the streams, for the soil, sand, and gravel wash much more easily from cleared land. Moreover, in the natural state, most of the timber that got into the river came from the undermining of banks on which it stood, and this usually did not float away but hung by the roots where it fell. But after the axmen got to work, every freshet brought down logs and rails which formed drifts at some places. Some logs stranded as the water went down, decayed, became waterlogged, and made bases for sand and gravel bars." (Dunn, 1910)

The Canal Era: 1825 - 1875

Erosional pollution as an important altering factor soon had a powerful ally when the state began an extensive, but unrealistic program of canal building from 1828 to the mid 1850's. Beginning at Fort Wayne in 1828, the Wabash and Erie Canal crept steadily westward toward the mouth of the Tippecanoe River, which was considered the head of navigation for the Wabash. The canal paralleled the Wabash River on the north between Fort Wayne and Delphi and on the south and east from Delphi to Terre Haute. At each tributary an elevated, waterproof aquaduct had to be constructed and feeder canals channeled into the Canal from tributary streams and wetlands. Frequently dams were constructed to ensure adequate water during the dry summer periods.

By 1834 about one thousand Irishmen were at work when they weren't drinking or fighting and the entire state was clamoring for canals. An appropriation was asked to open almost every stream in the state large enough to float a canoe (Esarey, 1912).

The upper portion of the Wabash and Erie Canal was in operation by July 4, 1835. However, the tolls were inadequate to keep it in repair and wooden aqueducts, which had to be constructed over every tributary, were already rotten. In 1836 construction was begun on the Whitewater canal and, when completed in 1839, it included two large dams on tributaries to provide water during dry periods. Also in 1836, several sections of canal were constructed on the White River and a 19 mile section on Pigeon Creek near Evansville which, when completed, went completely dry.

In August 1838, 859 Potawatomis were rounded up by General John Tipton and forced to march to Kansas, a trip during which more than a quarter of the group would perish. **"The enforced Indian migration allowed unsatiable whites to engage in the free enterprise of demolishing forests, polluting streams, and building drab towns. Settlements were aesthetically no improvement over tribal villages, but all were puffed with pride"** (Fatout, 1972).

Meanwhile, the Wabash and Erie Canal crept southward, reaching Lafayette in 1843 and Terre Haute in 1847. The canal was intended to connect with the Wabash River at Terre Haute. However, it was decided to connect it with the Ohio River via the lower Central Canal which was to be constructed to Indianapolis. Thus, the canal proceeded southeast to the Eel River, on past Worthington and Bloomfield, and to Maysville, west of Washington. It continued on south through Petersburg, crossed the Patoka and finally linked up with the canal at Pigeon Creek.

Throughout the 1840's difficulties were encountered in supplying sufficient water to that part of the canal south of Lafayette and, as a result, so-called "feeders" were developed from tributaries all along the canal. The problem was particularly aggravating below Terre Haute and dams were constructed across Splunge Creek, Adams Creek near Monrovia, and Birch creek at Saline City. The six square mile reservoir at the latter site was subject to frequent acts of sabotage because it was believed to be the cause of a malaria outbreak and finally was drained completely.
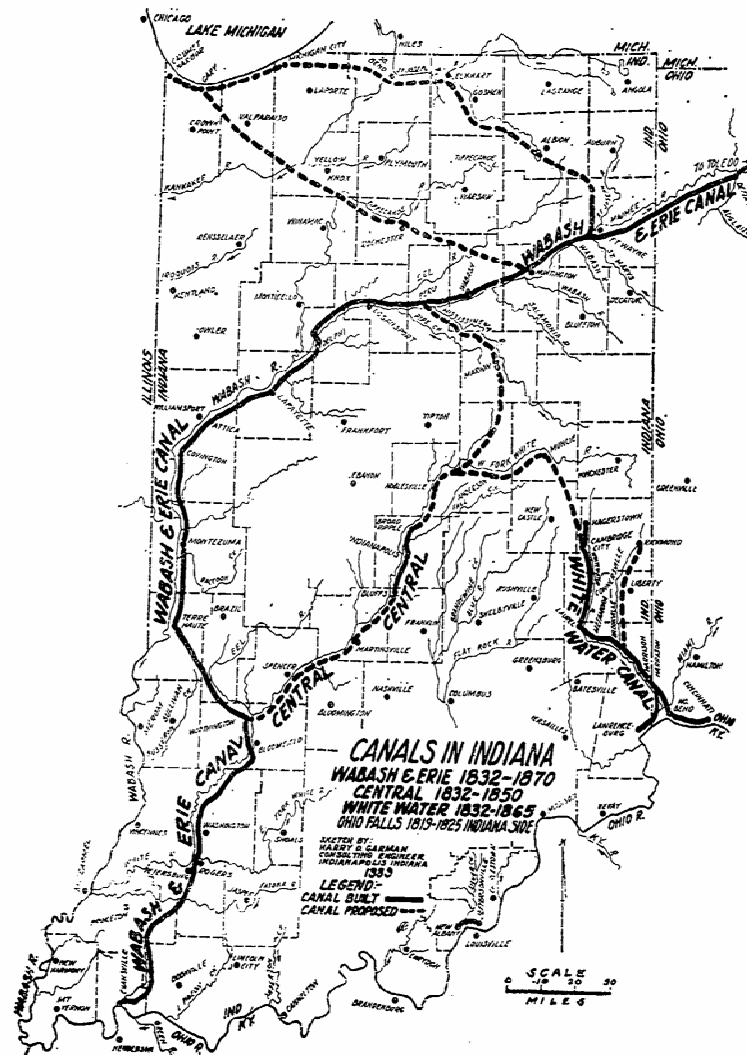
Figure 8: Indiana's canal system - constructed and proposed.

The Canal was directly instrumental in increasing the human population, enlarging farms by clearing and draining lands which before were not considered worth cultivation (Anonymous 1907). More than 5000 bushels of corn were shipped to Toledo in 1844. This increased 100 times in 1846, and amounted to 2,775,149 bushels in 1851. In that year also there were 9 flouring mills, 8 saw mills, 3 paper mills, 8 carding and fulling mills, 2 oil mills, and one iron foundry which were operating from water power obtained from the Canal. It at once became the highway for handling firewood and the manufacture and shipping of lumber was begun and maintained for a long time on an enormous scale. In addition, stone quarries arose and lime was manufactured.

The steam boats which made their way up the Wabash River were small compared to those which navigated the Ohio and Mississippi Rivers; vessels of 40, 80, or 100 tons were common (Cammack 1954). With increasing boat traffic on both the Wabash River and the canal Lafayette became an important commercial center. A city wharf was constructed which was already too small by 1853 to accommodate the demand by large and small craft. Steamboats over 100 tons were charged $4, those less than 100 tons $3, and other smaller craft $1 for 48 hours docking. Tippecanoe County also boasted 8 boat builders in 1850.

Many steamboats carried both freight and passengers, and some were showboats. The "Floating Palace", for example, was a floating circus with shows scheduled at Independence, Attica, and Covington on April 27, 28, and 29, 1853 (Cammack 1954).

Although the Wabash and Erie Canal was separate from the Wabash River, the aggregate damage to tributary stream habitat and the Wabash River itself during this period must have been significant, but can only be inferred since few descriptive records exist and, as it soon turned out, completely for naught. The zenith of Canal usage was 1850 when perhaps 500 boats navigated it. By this time repair or replacement was a regular feature of the Canal which had 9 aquaducts, 37 locks, 5 dams, 71 road bridges, and 139 culverts between the State Line and Perrysville alone. Water weeds clogging the Canal had to be removed repeatedly by a specially invented submarine mower. Cholera epidemics caused death and panic among residents and the Irish Canal laborers alike.

Spring floods in 1854 wrecked the Sugar Creek aquaduct and damaged another at Raccoon Creek. By this time, Indiana had about 1300 miles of operating railroads and another 1600 under construction. A worse repetition of floods, breaks, and droughts occurred in 1857 and 1858. A flood on the upper Wabash wrecked the Wildcat dam, carried away aquaducts over Wea and Shawnee Creeks, and breeched banks at a dozen places. Navigation was abandoned south of Terre Haute in 1860 and by 1870 little more than a succession of stagnant pools marked the site of the canal (Esarey, 1912), a casualty of gross fiscal mismanagement and competition from railroads.
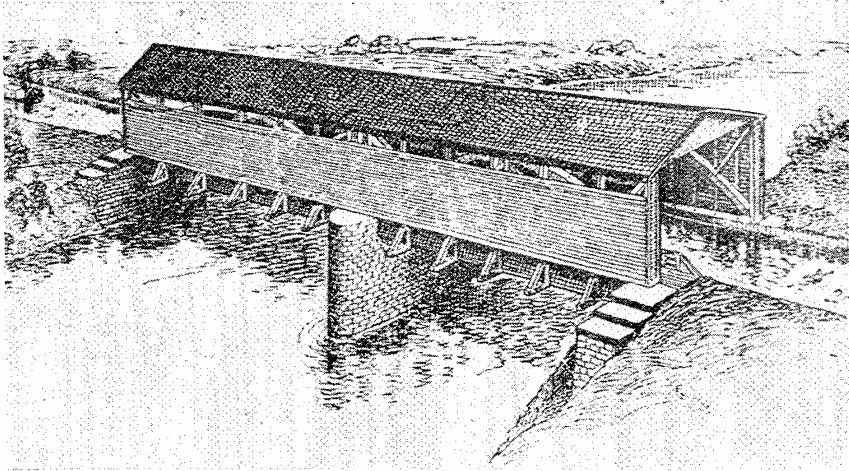
Figure 9: Aqueduct over the St. Mary's River at Fort Wayne, Indiana.
(Indiana Historical Society)
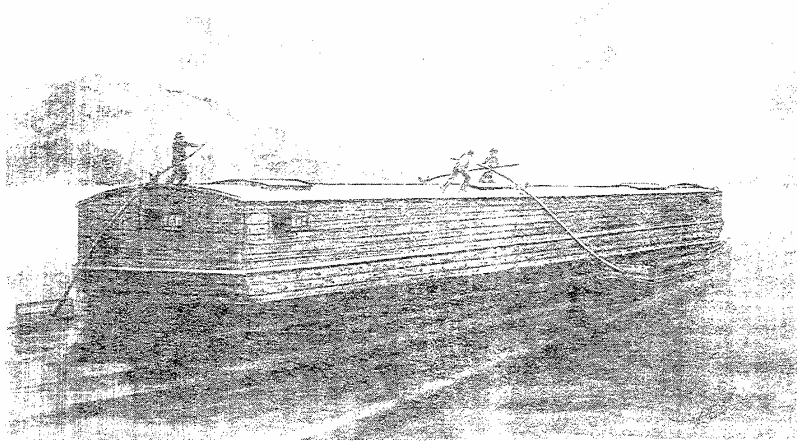
Figure 10: Covered flatboat used to convey goods downriver.

The Scientific Era: 1875 - 1990

The first reliable scientific records about the nature of the fish populations of the Wabash River date only from the 1870's when David Starr Jordan was just beginning in Indianapolis what was to become a distinguished career in higher education. While teaching at Shortridge High School and Butler University, Jordan and a colleague Herbert E. Copeland avidly collected fish from the White River and began studies of the life history of certain darters. They also collected at the Falls of the Ohio River near Jeffersonville, attempting to make sense out of the much earlier, hasty work of Rafinesque (1820). The effort expanded when Jordan moved to Indiana University.

Jordan's first paper (1875) (subsequently republished in the Biennial Report of State Fish Commission, 1892) described the various species he had personally examined from the White River, the Wabash River, and the Ohio River. Taxonomic uncertainty abounded. The list was updated and clarified by Jordan in 1877 and ultimately appeared with altered terminology in excellent summaries by Eigenmann and Beeson (1894) and Hay (1895).

Between 1875 and 1888 Jordan, together with his students and colleagues, collected fish from several sites on the Wabash River and its tributaries (Jenkins 1886, Evermann and Jenkins 1888). His assessment of the river appearance during this period includes the following statements: "The upper Wabash and most of its tributaries are clear streams, . . ." and "Towards its junction with the Ohio R. the Wabash becomes a large river with moderate current, the water not very clear, and the bottom covered with gravel and sand in which grow many water plants. The tributary streams are mostly sluggish and yellow with clay and mud" (Jordan 1890). Nevertheless, he found the "fish fauna of the Lower Wabash . . to be unexpectedly rich,. ." especially in the number of species of darters and their abundance. His collections of 1888 are usually accompanied by general assessments of abundance; eg. scarce, not rare, common, abundant, and very abundant.

Rolfe (in Forbes and Richardson 1920) stated "The waters of the Wabash are, like those of the Illinois and the Kaskaskia, commonly brown and opaque with suspended silt, never clearing even at the lowest stages; and the same is true of most of its tributary streams, especially those of the lower Illinoisan glaciation."

In his Presidential Address to the Indiana Academy of Science, Culbertson (1908) pointed out the association of deforestation in Southern Indiana with the erosion of soil and the pattern of flood and drought, and noted that "Streams that thirty years ago furnished abundant power for mills during ten months of the twelve now are even without flowing water for almost half the time." He went on to state that they have also "had a serious effect .. upon the animal life of these streams."

This early scientific period was dominated by scientists who relentlessly sought to collect and catalogue new species of fish wherever they could be found. It was evident that rivers at that time were not pristine, for Jordan noted in an address to the State Fish and Game Convention on December 19, 1899 "...That there never were

such (smallmouth) bass streams as in Indiana, and that White River is the best bass stream they have ever known. I think probably nothing better could be done--if we could devise a way--than to bring the bass back, and where there are now a dozen scattering fish put two or three thousand." The seeds of an extensive stocking program were thus already sown prior to 1900. A few years earlier, the First Annual Report of the Commission of Fisheries of Indiana (1883) carried Jordan's "Catalogue of the Fishes of Indiana" in an Appendix, but mostly discussed the coming availability of a great new species which would put fish back into Indiana lakes and streams--the carp. The Commissioners also discussed a recent fish-kill extending 20 miles downstream from Kokomo on Wildcat Creek, the result of pollution from a strawboard factory. If a new strawboard factory being constructed then at Anderson were to run its refuse into White River, they continued, "then it is "goodby fish" from Anderson to the Ohio River."

Thus, by the time Jordan arrived in Indiana in 1874, extensive alterations in the native fish populations had already occurred, alterations at first resulting from clearing land for fields and building dams for grist mills and a bit later the wholesale destruction of habitat in a gigantic state effort to provide better commercial links between the fledgling state of Indiana and the eastern seaboard. Jordan was in time, however, to witness the first side effects of industrial development in Indiana, a development which would super-impose an additional heavy burden on the waters of Indiana.

During the first decade of the 1900's Forbes and Richardson (1920) collected fish at about five sites on the lower Wabash River between the Embarrass River and the Little Wabash River. All of these early investigators employed the seine as their primary means of collecting fish and were, therefore, restricted to the more shallow, hard-bottomed sections of streams.

Shortly after these studies had been completed the problem of gross organic pollution and the human health aspects of pollution began to be perceived. "Before our population was so concentrated, sewage disposal by dilution was satisfactory from a physical standpoint, but now the condition of many of our streams has become such that for a part of the year at least, the odors from them are quite obnoxious and a nuisance to the cities and to the population living along the banks, as well as a menace to their health." (Craven 1912).

Following these early investigations there was a gap of nearly 40 years during which few studies were made. Blatchley (1938), a geologist by profession and a former student of Jordan, mostly summarized the earlier work. Not until the early 1940's did Gerking (1945) systematically collect fish at 412 sites scattered throughout Indiana in a comprehensive program, again using a quarter-inch mesh seine as the principal collecting technique. He seined 14 sites on the Wabash River downriver from Delphi including commercial gill-net captures. His comprehensive work established a firm basis for future comparative studies.

Speaking mainly of streams smaller than the Wabash River, Gerking wrote "Streams in the northern third of the state often run clear.." "Creeks of the central and southern part of Indiana are usually turbid and warm." "Many of the southwestern streams are slow-moving and usually carry a heavy load of suspended material."

Gerking (1945) found that the number of species of darters at sites sampled by the earlier investigators had diminished greatly since Jordan's time; only 3 species compared to 13 species at Delphi, no species compared to 4 species at Mr. Vernon, and 3 species compared to 12 species at New Harmony. He attributed this to increased siltation from soil erosion, but also had some observations on other possible influences from "city sewage, cannery waste, coal mine drainage, paper mill waste, and dairy-products factory waste." "The establishment of treatment methods of these wastes before their deposition in streams has done much to alleviate the problem, but much work remains to be done before pollution control is fully realized."

Visher (1944), addressing the causes for the increasing frequency of floods in Indiana, cited four main reasons: (1) abundant rainfall, (2) concentration of rainfall, (3) inadequate size and numbers of runoff channels, and (4) changes produced by man. "Deforestation has greatly increased runoff as have extensive drainage operations by open ditches and by tiles. Indiana has many miles of drainage ditches, 20,787 miles according to the 1930 Census of Drainage. Moreover,..there are..many thousand miles of small tile in addition to the 10,439 miles of large tile such as storm sewers...the extensive erosion of cultivated hillsides have carried large amounts of soil and other materials from the higher levels into the stream channels.."

It is safe to say that the investigative effort exerted on the Wabash River during the past 25 years far exceeds the combined efforts of the past. The research effort during this period has been directed primarily toward assessing man's activities as they influence elements of the river ecosystem. State environmental organizations such as the Department of Conservation and Environmental Protection Agency in Illinois and the Department of Natural Resources and Department of Environmental Management in Indiana have implemented extensive chemical sampling programs. Governmental and industrial sponsorship of research programs reached new heights. Immediate answers were sought for environmental questions which were often inadequately understood.

The fish populations of the Wabash River have been studied by our group since 1967, initially concentrating on thermal effects near Wabash River EGS north of Terre Haute, Ind. and Cayuga EGS near Cayuga, Indiana. In 1973 we extended the studies to longer stretches of the river because we realized that heat was but one of many environmental influences on the biota of the river. Since 1978 we have studied nearly 170 miles of river extending from Delphi, Ind. on the north (RM 330) to Merom, Ind. on the south (RM 161). Most of the following sections summarize this research up to 1993.

PHYSICAL ATTRIBUTES OF THE WABASH RIVER

The Wabash River originates in the agricultural drains and ditches in northwestern Ohio near Fort Recovery at an altitude of about 267 m and flows southwesterly 764 km to enter the Ohio River at an altitude of about 97 m near Mount Carmel, Illinois (Fig. 11). It flows freely throughout its length except for Huntington Reservoir at river kilometer (rkm) 662. Its average rate of descent is about 0.22 m/km, but the river is best divided into two sections: a relatively steep upper section with a rate of fall of 0.454 m/km and the longer, lower section with a rate of fall of only 0.123 m/km (Figure 12). The transition between these dissimilar segments is abrupt and occurs at about rkm 570 (RM 356) near Logansport, Indiana.

The Wabash River basin is the largest Ohio River tributary basin, except for the Tennessee River basin, with a total land area of 85,500 km². It receives water from 62,000 km² of Indiana, 22,540 km² of Illinois, and 740 km² of Ohio. The Wabash River drains 65.6% of Indiana's area (Clark 1980). Except for Lake Michigan, it is the largest body of water in Indiana, with more than 100 km² of surface area.

About two-thirds of the watershed is in agricultural cropland (Figure 13), the highest proportion within the Ohio River basin (ORSANCO 1990). An additional 8.2% is in pasture or grassland. Forests or woodland constitutes only 13.5% of the basin's land area, the second smallest proportion within the Ohio River basin. Agricultural development is considerably greater in the upper half of the basin. The lower half of the basin has a greater percentage of forests, as well as most of the surface coal mines. The upper half of the Wabash River lies in the **Eastern Corn Belt Plains** Ecoregion, while the lower half is contained within the **Interior River Lowland** Ecoregion (Omernik and Gallant 1988).

During the Pleistocene Epoch, glaciers moved into Indiana at least three times, with the Illinoian boundary extending nearly to the mouth of the Wabash River. This resulted in deposits of glacial drift from less than 15 m thick in the south to more than 90 m in the north. Extensive till deposits cover the northern basin with sand and gravel outwash deposits occurring along major rivers and streams.

The middle Wabash River flows through an extensive deposit of loess. The major bedrock consists of Pennsylvanian and Mississippian rocks.

Homoya et al. (1986) delineated 12 natural regions of Indiana, 11 of which are based importantly on the dominant natural vegetation composition. Their **Central Till Plain** natural region, which roughly corresponds with the **Eastern Corn Belt Plains** Ecoregion, is subdivided into three Sections: **Bluffton Till Plain, Tipton Till Plain,** and **Entrenched Valley.**

The Wabash River flows within the **Bluffton Till Plain** from its origin at rkm 764 (RM 475) to rkm 570 (RM 354) near Logansport, Indiana. From there to rkm 370 (RM 230) near Clinton, Indiana, it is contained within the **Entrenched Valley,** and for the remainder of its journey it flows through the **Southern Bottom-lands** natural region.

Homoya et al. (1986) also distinguished a separate **Big Rivers** natural region that includes the lower Wabash from about rkm 467 (RM 290) near Attica, Indiana to its mouth and also the White River from the confluence of the East and West forks to its mouth.
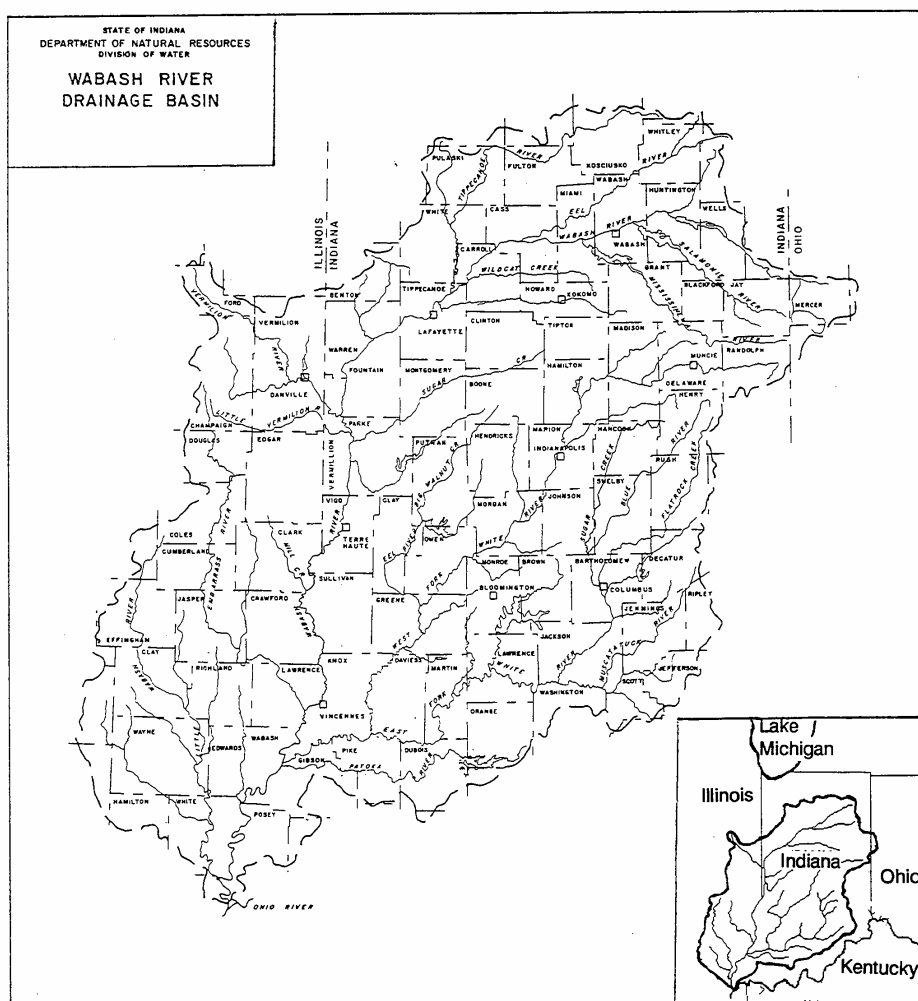
Figure 11: The Wabash River drainage basin
(Indiana Department of Natural Resources, Division of Water)
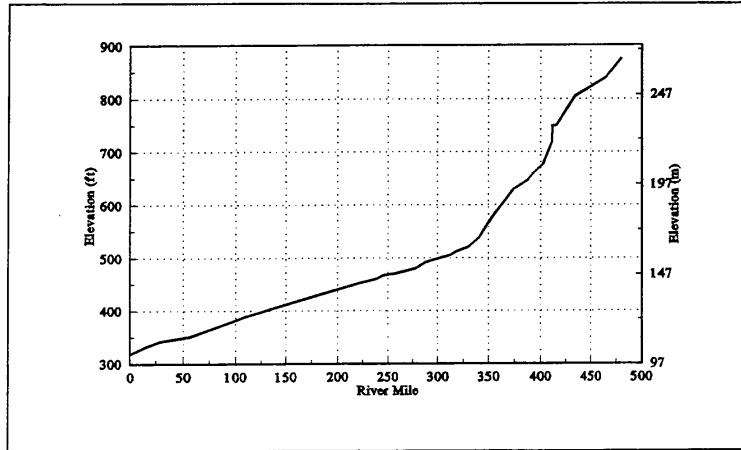
Figure 12: Elevation profile of the Wabash River.
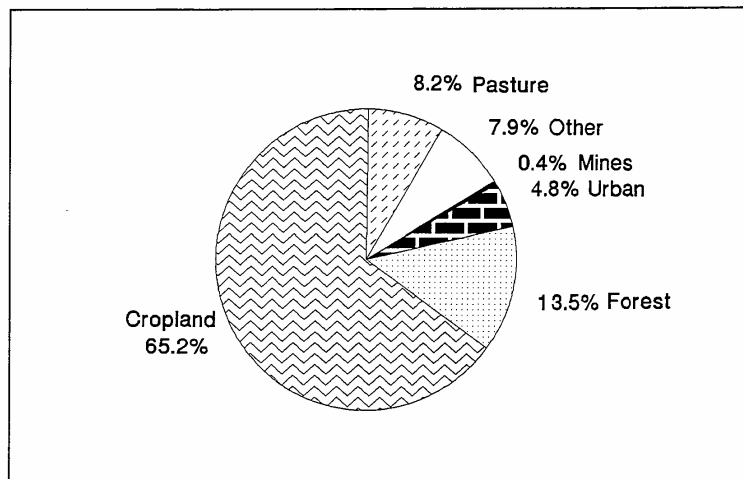
Figure 13: Primary landuse in the Wabash River basin.

Flow Regime of the Wabash River

In terms of average discharge, the Wabash River is about one-fourth the size of the Ohio River where the two rivers meet. On the average nearly 850 m³/s is discharged into the Ohio River (Todd 1970), making the Wabash River the twelfth largest river in the United States. The White River (drainage basin area = 29,394 km²), a major tributary, is 69.1% as large as the Wabash River basin (42,538 km²) where they join at rkm 154 (RM 96). In terms of discharge, however, the two rivers produce nearly the same average volume of water, 335.6 m³/s for the White River and 341.5 m³/s for the Wabash River (Arvin 1989).

Although Huntington Reservoir is the only mainstem reservoir, water discharge in the upper Wabash River is influenced by the Salamonie and Mississinewa Reservoirs. Annual discharge in the upper river (Peru) is lower and more stable than more southerly stations (Figure 14).

Significant contributions of water between Peru and Lafayette are made by the Eel and Tippecanoe rivers and Wildcat Creek. Lakes Shaffer and Freeman located on the lower Tippecanoe River not only influence the flow of the Wabash River, but also provide a source of clarified water.
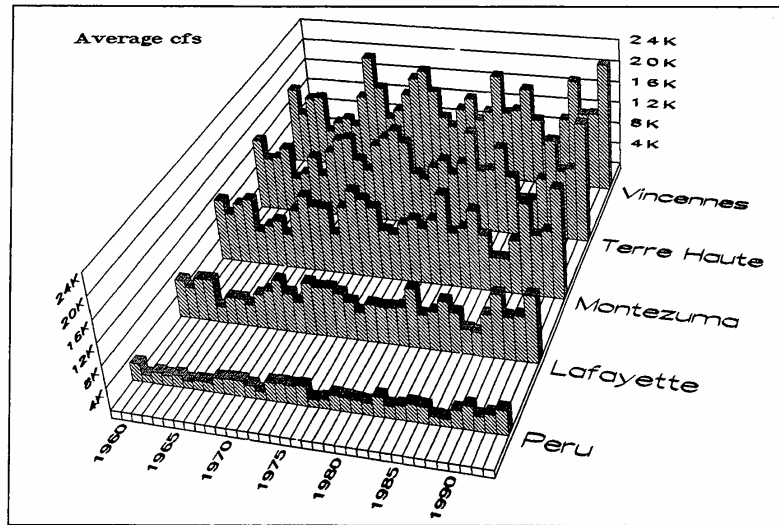
Figure 14: Mean annual discharge of the Wabash River at Peru, Lafayette, Montezuma, Terre Haute and Vincennes from 1960 through 1993.

Big Pine Creek, Big Vermilion River, Sugar Creek, and Big Raccoon Creek enter the Wabash River between Lafayette and Terre Haute. Reservoirs are found only on the Middle Fork of Big Vermilion River and Big Raccoon Creek (Mansfield Reservoir).

Seasonal variation in discharge is substantial (Figure 15). The highest average discharge in March or April (5,000 cfs) is about four times larger than the flow in August, September, or October (18,000 - 20,000 cfs).

River discharge based on seasonal or annual periods of time is valuable information for some purposes, for example, in determining the yield of water from a particular watershed. It may even be useful in characterizing rivers in a general way. However, it is limited in terms of its ecological value.

Rivers rarely flow at a steady, average rate. Indeed, the variability of discharge or flow in most rivers is one of their most distinguishing and vexing characteristics. Ecologically, rivers are among the least stable systems on our planet and, because of this, they are among the most difficult biological systems to study.

The Wabash River is unusual in flowing unconstrained for the last 662 km (411.4 miles) of its journey south to the Ohio River. Few rivers in the United States can make that claim, especially rivers east of the Mississippi River.

The presence of reservoirs on some tributaries, in addition to the single mainstem reservoir (Huntington Lake), moderate flow variability to a limited extent. However, most of these reservoirs are small because of
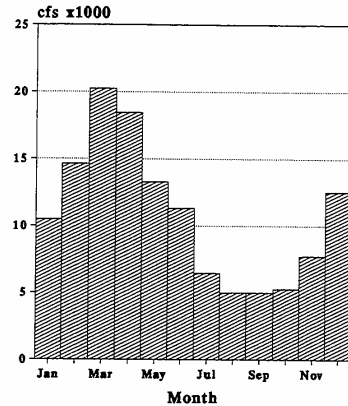
Figure 15: Mean monthly discharge of the Wabash River at Montezuma 1970-1989

the gently sloping topography. For example, Huntington Reservoir was constructed in 1969 and is approximately 905 acres in surface area (Clark 1980). Salamonie Lake was completed in 1966 and is approximately 2,800 acres in surface area. Mississinewa Lake, completed a year later, is approximately 3,180 acres. Lakes Shafer and Freeman on lower Tippecanoe River are less than 3,000 acres combined.

Variability in river flow affects all of the biotic components of lotic ecosystems. Sections of rivers with less variable rates of discharge over time tend to have greater fish species richness than other more changeable sections (Horwitz 1978).

The daily flow of the Wabash River measured at Montezuma during the summer is shown in Figure 16. The superimposed horizontal bars indicate electrofishing periods. Electrofishing success under different flow situations resulted in

developing a collecting criteria based on river level. Collecting would be initiated only when the river dropped to certain levels as determined by U.S.G.S. gauging stations at Lafayette and Terre Haute, Indiana. Short periods of collecting were conducted on short segments of river which were suitably low at the time. Long periods usually indicate complete coverage through the entire middle Wabash River.

Jim Thayer, Rick Wright, and Bob Gammon moving downriver
to the next collecting station.
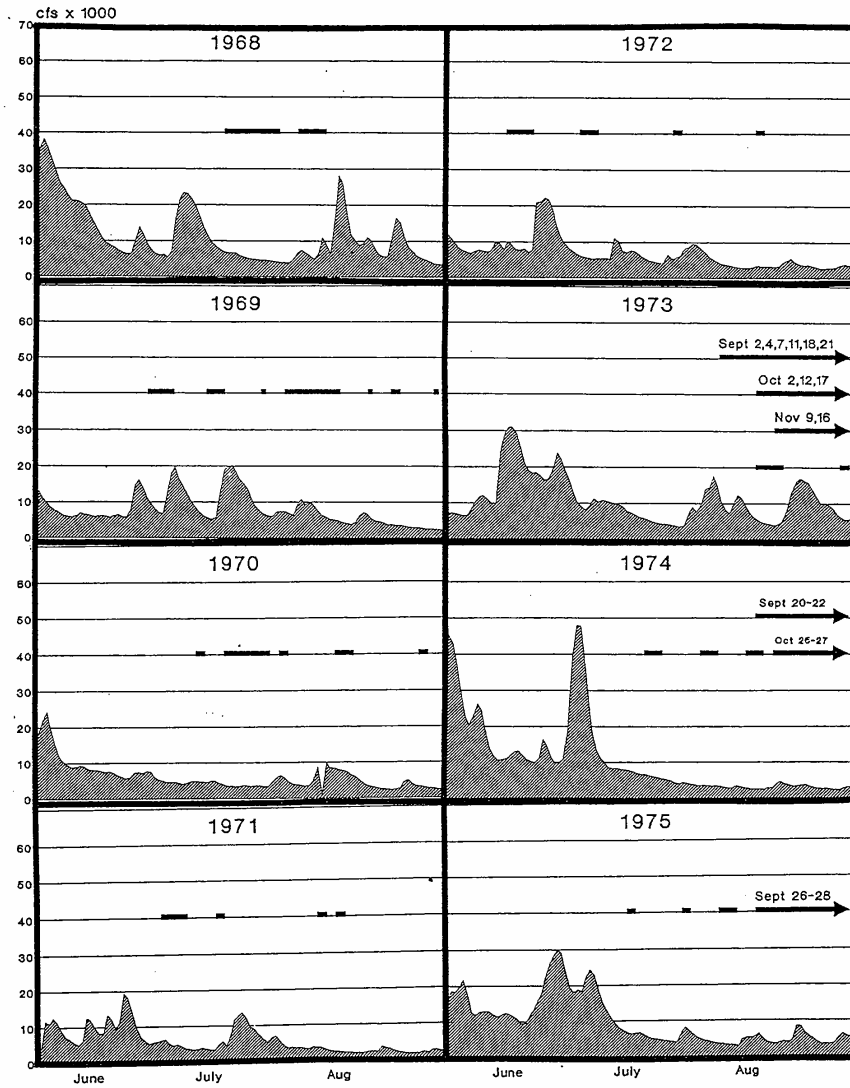
Figure 16: Daily discharge (cfs x 10^3) of the Wabash River as measured by the U.S.G.S. gauging station at Montezuma, Indiana from May 23 to August 31.
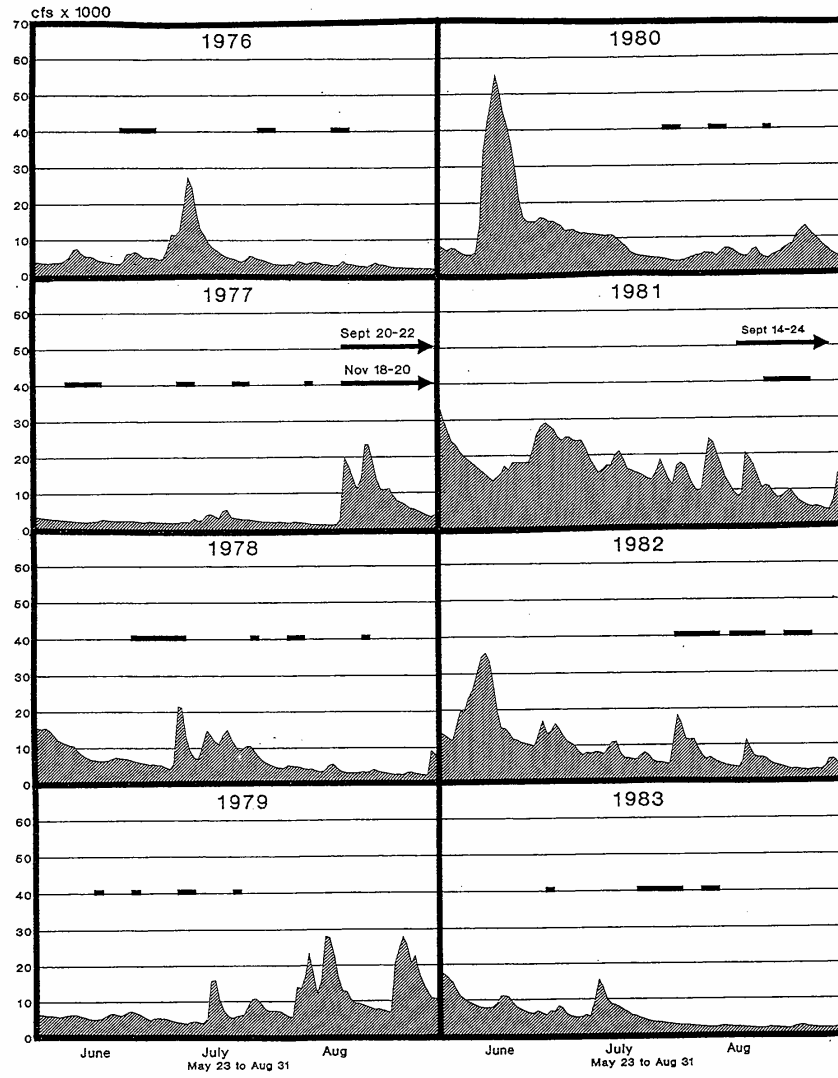
Figure 16: (continued)
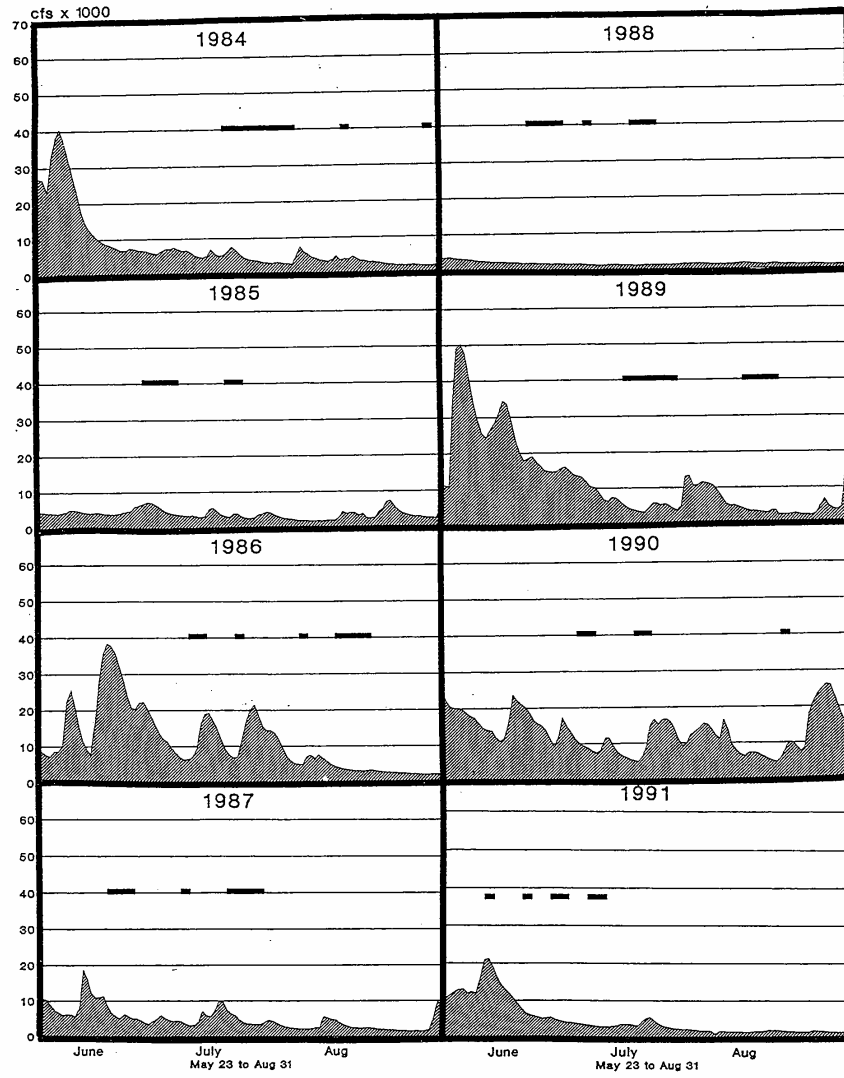
Figure 16: (continued)
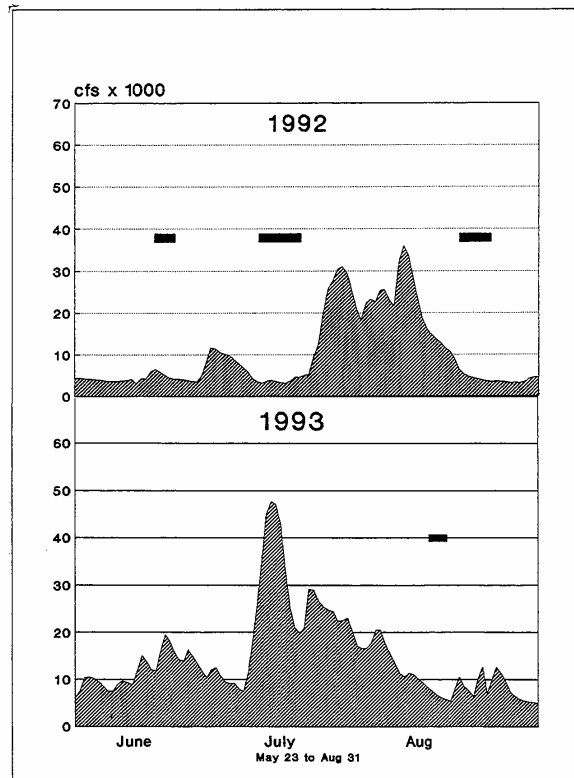
Figure 16: (continued)

Temperature

Normal water temperatures are usually near 0°C during the winter months, but temperatures rise steadily from March through June (Figure 17). Temperatures often exceed 25°C during the low-flow months of July, August, and early September, and sometimes exceed 32°C. Water temperatures decline sharply in October.

The diurnal changes in water temperature of flowing waters is normally less extreme than for air temperature. The temperature differential between air and water may exceed 10-15°C although the daily thermal range of rivers is usually less than 4°C (9°F). A typical annual thermal pattern of the Wabash River is shown in Figure 17. Data was collected by the U.S. Geological Survey at Lafayette, Indiana in 1969 and includes weekly mean and weekly high and low temperatures. During winter the water temperature is usually at or close to 0°C with ice forming during colder periods.

Reservoirs, lakes, and ponds usually exhibit thermal stratification during the summer. However, this rarely occurs in flowing waters because of mixing by currents. Temperatures in unshaded shallow sections such as along edges and in riffles may rise appreciably. The biotic residents of rivers and streams are provided with a heterogeneous thermal environment horizontally, however. Cool water from shaded tributaries together with riverside springs and upwelling ground water provide valuable refugia during periods of thermal stress.

Many research reports have been written on the effects of electric generating stations (EGS) on the biota of the Wabash and White Rivers. A list for the Wabash River may be found at the end of this report. The overall impact of the Cayuga and Wabash River EGSs is considered later.
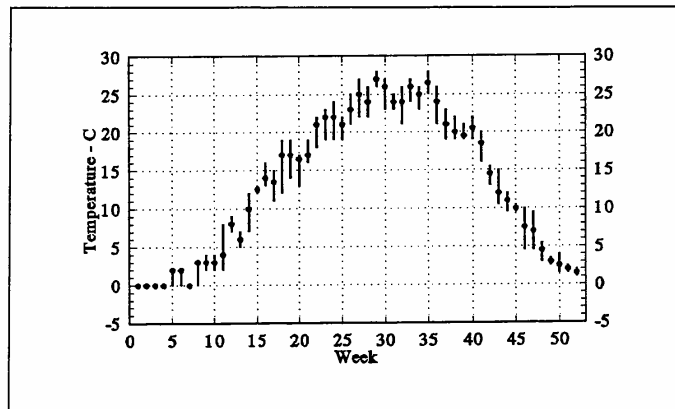
Figure 17: Pattern of thermal change in the Wabash River at Lafayette, Indiana in 1969.

Suspended Solids Concentration

The turbidity of most rivers is caused by a heterogeneous mixture of particulate materials in suspension. Some is inorganic matter such as sand, silt, and clay. Some is dead organic matter including bits of leaves and microscopically small fragments of decomposing organic matter. In some rivers living phytoplankton and zooplankton are carried along by the current as part of the suspended solids load. Rivers originating from melting glaciers carry large loads of mostly inorganic glacial "flour". Rivers draining swamps or bogs are often rootbeer brown in color because of colloidal humic organic substances in suspension.

The suspended solids concentration (SSC) is of importance both ecologically and socially. The deposition of part of the suspended solids load may negatively influence reproductive success for some species of fishes. For some fish and most benthic organisms at least part of the SS load is food in the form of detritus, bits of dead organic matter, and phytoplankton. For other species of fishes the turbidity which accompanies the SS load may severely limit visual capabilities and interferes with food location. Most of the so-called "sport" fishes such as smallmouth bass (*Micropterus dolomieui*), spotted bass (*Micropterus punctulatus*), sauger (*Stizostedion canadense*), white bass (*Morone chrysops*), and crappie (*Pomoxis sp.*) are included in this category. Additional non-game predaceous fishes which primarily locate food visually include goldeye (*Hiodon alosoides*), mooneye (*Hiodon tergisus*), and skipjack herring (*Alosa chrysochloris*).

Part of the SS load consists of decomposing organic matter and phyto-plankton. This may influence the biotic community through its effect on the dissolved oxygen concentration, an aspect which will be addressed in the next section.

The SS load is also important to all human communities which utilize surface waters for human consumption. Suspended solids have to be removed in treating the water for human consumption. High concentrations of suspended solids in rivers or lakes are also aesthetically undesirable from a recreational consumption perspective. Few people care to swim, canoe, or fish in turbid water which is perceived as being "dirty" water.

The average annual suspended solids concentration (SSC) in different sections of the Wabash River during the period 1977-1987 is shown in Figure 18. The SSC doubles in concentration from Peru to Vincennes. It increases further by the time the river reaches the Ohio River. The observed pattern of increasing SSC with increasing river size is probably typical of most rivers.

Crawford, C.G. and L.J. Mansue (1988) examined partial-records for the Wabash River at Lafayette for the years 1964 through 1982 (N = 59). A statistically significant increase occurred in discharge (P<0.05), but no change over time was indicated for SSC, flow-adjusted SSC, or suspended-sediment discharge. The median SSC was 66 mg/L (mean = 87 mg/L; range = 6 to 980 mg/L). The median suspended-sediment discharge was 714 tons/day (range = 13 - 81,500 tons/day).
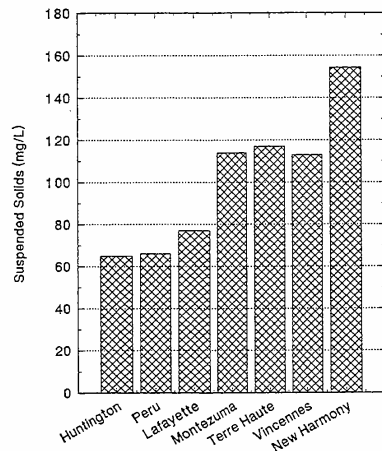
Figure 18: Mean suspended solids concentration (mg/l) 1977 - 1987.

The daily SS load at Lafayette was examined for a shorter period during 1978-80 (N = 784). The median suspended-sediment concentration at this time was 45 mg/L (mean = 61 mg/L; range = 6 to 677 mg/L) and the median suspended-sediment discharge was 1,341 tons/day (mean = 1,882 tons/day; range = 21 to 79,600 tons/day).

The SSC is strongly influenced by river discharge and both parameters are related to rainfall events in complicated fashion. Crawford and Mansue (1988) used partial-records for the period 1951 to 1980 to mathematically describe the relation between water discharge and suspended-solids discharge for the Wabash River at Lafayette as a first-order polynomial equation:

$$\text{Ln } Q_s = -6.5993 + 1.5832(\text{Ln } Q_w)$$

where LnQ_s is the natural logarithm of the suspended-solids discharge in tons per day; and

LnQ_w is the natural logarithm of the water discharge in cubic feet per second.

HydroQual (1984) examined the SSC and SS load as a function of Wabash River flow for the summer period only, using ISBH data from 1968 to 1981. Figure indicates the SS load as a function of river flow and gives the equation describing SSC as a function of river flow for three flow regimes (Q = flow in cfs):

(a) for flows less than 2500 cfs
   $\text{SSC(mg/L)} = 5800 \times (1.00132^Q/Q)$

(b) for flows between 2500 and 6300 cfs
   $\text{SSC(mg/L)} = 5600 \times (1.000303^Q/Q)$

(c) for flows exceeding 6300 cfs
   $\text{SSC(mg/L)} = 131,000 \times (1.000185^Q/Q)$

An analysis of the particle sizes of suspended-sediment was performed on 6 samples taken when the river discharge was between 5,220 and 23,600 cfs (Crawford and Mansue 1988). The SSC ranged from 98 to 185 mg/L. Particles less than 0.004 mm in diameter (clay) constituted 68% of the SS load by weight; particles measuring between 0.004 mm and 0.062 mm in diameter (silt) constituted an additional 27% by weight. Only 5% of the SS load consisted of particles greater than 0.062 mm in diameter. No estimates of bed-load were made.

ISBH SUMMER WABASH DATA
1968-1981

① FOR FLOW < 2500 cfs
SS (mg/l) = 5800 x $\left(\dfrac{1.00132}{Q}\right)^{Q}$

② FOR 2500 < FLOW < 6300 cfs
SS (mg/l) = 5600 x $\left(\dfrac{1.000303}{Q}\right)^{Q}$

③ FOR FLOW > 6300 cfs
SS (mg/l) = 131,000 x $\left(\dfrac{1.000185}{Q}\right)^{Q}$
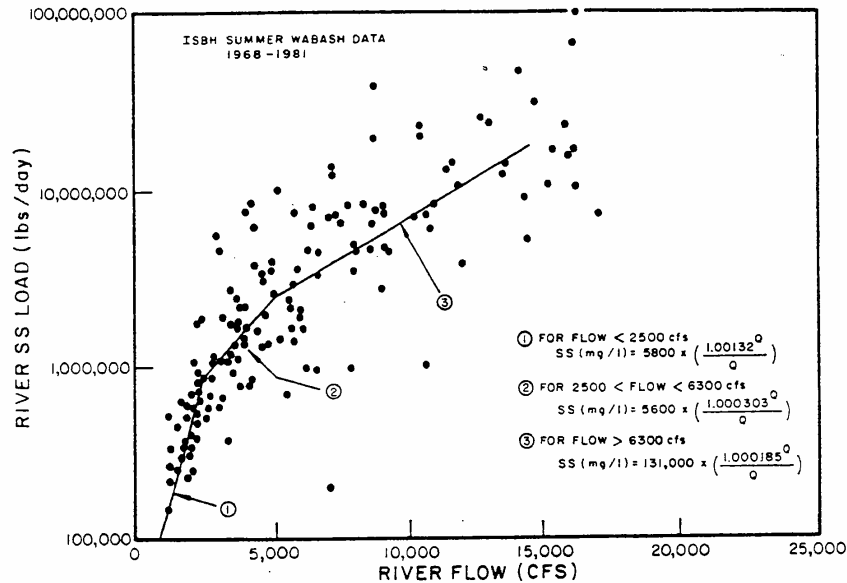
Figure 19: Suspended solids loads (lbs/day) as a function of river discharge (cfs) based on Indiana State Board of Health data 1968 - 1981.

Partial-records (N=67) for the Wabash River at New Harmony, Indiana for the years 1975 through 1984 indicated a median SSC of 116 mg/L (mean = 150 mg/L; range: 27 - 601 mg/L) and a median SS discharge of 5.66 x 10^6 kilograms per day (6,240 tons/day with a range of 391 to 76,600 tons/day).

Smith et al. (1987) analyzed water-quality trends in major U.S. rivers for the period 1974 - 1981 and state that an increase in SSC for the Ohio River occurred over this period of time. Sediment increases occurred

generally wherever cropland erosion rates were high (more than 5,600 kilograms per hectare per year). Crawford and Mansue (1987) estimated that for the Wabash River above Lafayette the mean annual suspended-sediment yield was 474 kg/ha (135 tons/mi^2)

The SS load strongly influences the depth to which light penetrates. The relationship of extinction coefficient values of Wabash River water to SS loads characteristic of summer flows in 1981 and 1982 was determined by HydroQual (1984) and is shown in Figure 20.
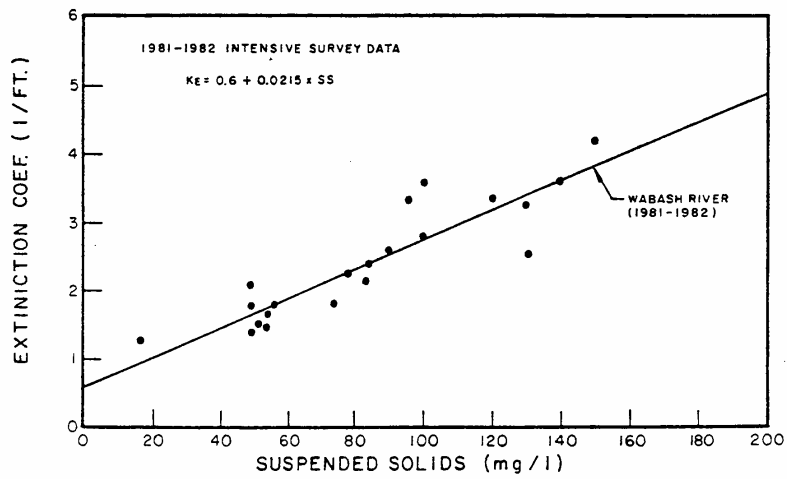
Figure 20: Extinction coefficients as a function of suspended solids concentration (mg/l) in the Wabash River, summers 1981 - 1982.
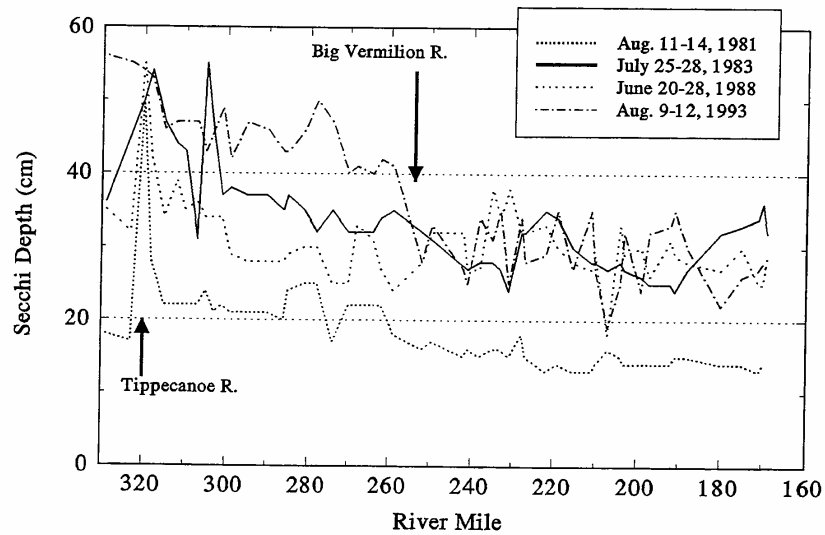
Figure 21: Profiles of Secchi depth (cm) of the Wabash River.

The secchi disk is an eminently practical device for determining water clarity. It is a simple plate with alternating black and white quarters. The Secchi depth (Z_{SD}) is the depth below the surface at which the black and white quarters disappear from view. Whatever its limitations, the Secchi disk is well adapted to survive the environmental rigors of the fish collecting boat, compared to more complicated instruments. It is portable, durable, and easy to use. The fish collecting crew routinely determines this parameter at all fish collecting stations since 1981.

Profiles of the Secchi depth along the middle Wabash River during the low-flow summers of 1983 and 1988 are presented in Figure 21, together with two other periods. All but one of these profiles were taken during very low and stable discharge conditions. The profile obtained during the period August 11 to 14, 1981 was taken when the discharge rate was greater than normal.

The profile obtained in 1993 followed the infamous flood which had scoured away fine sediments and benthic algae.

The increased clarity of water at about RM 320 marks the entry of the Tippecanoe River into the Wabash River. Two reservoirs, Lake Schaffer and Lake Freeman, act as settling basins to remove suspended solids before the clarified water enters the Wabash River. There are secondary increases in clarity where Wildcat Creek and Sugar Creek join the Wabash River, but only during some years.

There is also a decrease in water clarity where the Big Vermilion River enters the Wabash River. This decrease was especially evident in August, 1993 after the flood waters had receded and accentuated the division of the Wabash River into a clearer portion above Big Vermilion River and a more turbid portion below.

River Channel Morphology

A thorough analysis of river channel morphology for the middle Wabash River has not yet been made. However, studies were initiated in more limited segments because of fish kills which occurred in 1977 and 1983 between the Cayuga Electric Generating Station and Montezuma, Indiana (Gammon and Reidy 1981).

Determinations of sediment oxygen demand (SOD) indicated relatively high rates of oxygen uptake by sediments in this part of the river as compared to reaches further upriver or downriver (Bell 1983). Additionally, it was determined that when discharge was low algal densities increased and particulate sedimentation rates were relatively high in this same section of river (Parke 1985; Parke and Gammon 1986). The deposition of suspended materials, including algae, and its subsequent decomposition apparently led to a depression of dissolved oxygen (DO) concentrations in the water column.

Although one possible cause of the problem was entrainment mortality of phytoplankton by the Cayuga EGS and its subsequent deposition and decomposition, another potential contributor was suspected to be river morphology. Large deposits of gravel at the mouth of Sugar Creek partially block the flow of the Wabash River during low-flow periods creating a more lentic environment which would promote deposition of particulates normally in suspension, hence the river channel studies.

Width, mean depth, and cross-sectional areas of the Wabash River were determined annually at 0.5 km intervals from 1985 through 1988. The first series was taken from the mouth of Big Vermilion

River to Montezuma, Indiana on July 29 and 30, 1985 when the river discharge averaged 51 m^3/sec (1880 cfs) at Montezuma. The studies were extended from Montezuma, Indiana to I-70 bridge south of Terre Haute, Indiana on August 11, 12, and 13, 1986 when the river was gradually rising and discharge averaged 86 m^3/sec (3170 cfs) during the three-day period.

The measurements were repeated on August 19 - 24, 1987 using the same transects between the State Road 234 bridge east of Cayuga, Indiana and Clinton, Indiana. The discharge of the river at Montezuma, Indiana averaged 43.8 m^3/sec (1615 cfs) and was gradually decreasing during this period.

In 1988 the Wabash River did not flood during spring and by mid-May the river had already stabilized at levels low enough for fish studies to be initiated. During the ensuing drought the river discharge continued to decline throughout the summer and early fall. Shoal areas normally covered by at least a few inches of water became exposed early in the summer and were soon colonized by terrestrial vegetation which grew two to three feet high by August. Even the steep, unscoured mud and clay banks turned green with weedy growth.

While the low 1988 summer discharge was far from ideal for collecting fish by electrofishing, conditions were nearly perfect for measuring river morphology during extremely low flows. River discharge was estimated to be 34.1 m^3/sec (1258 cfs) on July 19, August 1, and August 2, 1988, when breadth, depth, and cross-sectional area was measured from Big Vermilion River to Clinton, Indiana.

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River bottom contours were determined using a Lowrance Model X-155B sonar transported by boat which motored at a constant speed from one shore to the other. The depth of the river was measured directly in a few places where it was too shallow for the boat. River width was measured optically using a Leitz rangefinder.

The cross-sectional areas were estimated from the graph contours using a K. and E. Compensating Polar Planimeter. Mean depth was computed by dividing cross-sectional area by channel width. The profile of the cross-sectional areas determined in 1988 is shown in Figure 22. This profile was divided into six segments for comparative

purposes. The segments upstream from Sugar Creek and Clinton, Indiana both prominently exhibit the relatively large cross-sectional areas which are characteristic of "pool" morphology.

Average cross-sectional areas, depths, and widths for each segment in 1988 are shown in Figure 23. The same general pattern existed in 1985, 1986, and 1987, albeit with slightly higher values for each parameter. The river was narrowest and had the smallest cross-sectional area from Big Vermilion River to the Cayuga Electric Generating Station discharge. The section of river between Montezuma, Indiana and the Eli Lilly-Clinton plant was widest and shallowest .
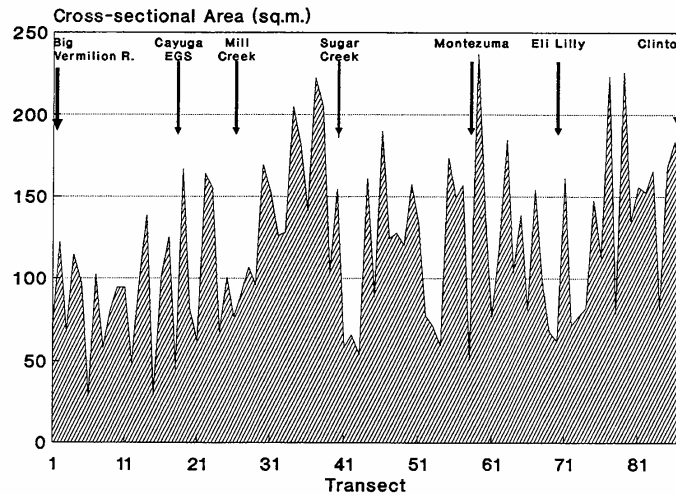
Figure 22: Cross-sectional area of the Wabash River
from Big Vermillion River to Clinton, Indiana in 1988.

These measurements represent low-flow conditions and provide indications of the changes in river morphology which exist at critical low-flows. Some anomalies are apparent when the channel morphology which existed in 1987 (low-flow) is compared to that of 1988 (very low-flow). The mean width decreased at very low-flows most places except between Montezuma, Indiana and Eli Lilly-Clinton where it changed little. The mean depth of the "pooled" segments actually increased in 1988 compared to 1987, although it decreased in the other segments.

In 1988 the segment from Mill Creek to Sugar Creek was about 50% greater in cross-sectional area than the segments from Big Vermillion River to Mill Creek. The lower segment from Eli Lilly-Clinton to Clinton, Indiana was also about 30% larger in cross-sectional area than the segment from Montezuma, Indiana to Eli Lilly-Clinton. This relationship was also present in 1987, although it was less evident.

The mean width of the river increased steadily as it flowed south and, as mentioned previously, was particularly wide and shallow in the segment extending from Montezuma, Indiana to Eli Lilly-Clinton. The river channel downriver from Clinton, Indiana was examined only in 1986. At that time there were no segments which were "pooled". However, the river at Terre Haute, Indiana was unusually wide in places.

Neil Parke determines the width of the river with a rangefinder.

Mean Width - 1988

B.Verm. R to Cay.EGS	92.9
Cay. dis. to Mill Ck	104
Mill Ck to Sugar Ck	101.4
Sugar Ck to Mont.	125.6
Mont. to Eli Lilly	142
Eli L. to Clinton	102.4

0 50 100 150 200

▨ Width (m)

Mean Depth - 1988

B.Verm. R to Cay.EGS	0.96
Cay. dis. to Mill Ck	1.09
Mill Ck to Sugar Ck	1.54
Sugar Ck to Mont.	1
Mont. to Eli Lilly	0.88
Eli L. to Clinton	1.55

0 0.5 1 1.5 2

▨ Mean Depth (m)

Cross-sectional Area - 1988

B.Verm. R to Cay.EGS	89.5
Cay. dis. to Mill Ck	112.8
Mill Ck to Sugar Ck	156
Sugar Ck to Mont.	125.2
Mont. to Eli Lilly	124.2
Eli L. to Clinton	158.3

0 50 100 150 200 250

▨ C.S. Area (sq. m.)

Figure 23: Mean width, depth, and cross-sectional areas of six segments of the Wabash River between Big Vermillion River and Clinton, Indiana.

The Riparian Wetland Corridor

Riparian wetlands found throughout Indiana, including the middle Wabash River, consist primarily of the bottomland forests which flank the river. The original riparian community was probably dominated by tree species such as those found by Lindsey (1962) at Beall Woods (now Beall Woods State Park) near Keensburg, Illinois. He found that a high proportion of trees exceeded 76 cm (30 inches) in basal diameter. A year earlier he found that none of the stands which were examined along the Wabash River from Logansport, Indiana to Vincennes, Indiana represented the original, presettlement type (Lindsey et al. 1961) and ". . .it appeared that every example of such superb timber had been sacrificed. .".

Lindsey et al (1961) found that the chief species on first bottoms or lowest terrace were black willow (*Salix nigra*), silver maple (*Acer saccharinum*), American elm (*Ulmus americana*), and cottonwood (*Populus deltoides*) with important contributions from sycamore (*Plantanus occidentalis*), red elm (*Ulmus rubra*), cork elm (*Ulmus thomasi*), box-elder (*Acer negundo*), white ash (*Fraxinus americana*), and hackberry (*Celtis occidentalis*). On the less frequently flooded second terraces there was a shift to species which were less water tolerant, but more shade tolerant.

Lindsey et al. (1961) also reported that on the cut banks of the Wabash and Tippecanoe rivers, rapid erosion undermined and toppled trees of any size, but erosion proceeded slowly where some old elms sheathed the steeply sloping bank with a network of exposed living roots, mostly several centimeters in diameter which effectively protected both trees and banks.

Representatives of these same species still border Indiana's streams and rivers today. However, ". . . the floodplains were rapidly cleared" after settlers discovered that rich bottomlands would grow the best corn after the trees had been cleared" (Petty and Jackson, 1966). As a result, little of the original ecotone remains to buffer water courses from agricultural activities.

The first riparian survey was undertaken in 1983 because we observed an accelerated rate of tree cutting along the river corridor during the previous several years. The middle Wabash River includes approximately 265 km (165 miles) of river between Delphi, Indiana and Merom, Indiana. For comparative purposes of this section of river is subdivided into 12 Reaches as indicated in Table 1.

Surveys of the Wabash River near-shore riparian wetlands were made during the summer of 1983 and repeated in 1994. The 1983 evaluation was made from the river's surface by boat. A boat was also used in 1994 for examining river banks between Delphi, Indiana and Montezuma, Indiana, while the survey from Montezuma to Merom, Indiana was made using a light plane.

Three classes of riparian condition were determined: (1) banks which were devoid of trees (although some brushy growth might be present), (2) banks with one or two trees growing between the river edge and fields beyond, and (3) banks with more than two trees.

Distinguishing between categories (2) and (3) was sometimes difficult and created most judgmental problems. Few pastures or

Table 1: Location of riparian Reaches of the middle Wabash River.

Reach	River Mile (Rkm)	Description of Location
1	330 to 313 (531-502)	Delphi to north Lafayette, Ind.
2	312 to 302 (501-486)	Lafayette & W. Lafayette area
3	301 to 286 (485-460)	Lafayette to Attica, Ind.
4	285 to 269 (459-433)	Attica to Covington, Ind.
5	268 to 251 (432-404)	Covington to Coal Creek
6	251 to 246 (404-396)	Cayuga Elec. Generating Station
7	247 to 233 (396-375)	Cayuga EGS to E. Lilly, Clinton
8	232 to 218 (374-351)	E.Lilly, Clinton to Otter Creek
9	217 to 212 (349-341)	Wabash Elec. Generating Station
10	213 to 203 (343-327)	Terre Haute, Ind. area
11	202 to 186 (325-299)	Terre Haute STP to Darwin, Ill.
12	185 to 160 (298-257)	Darwin, IL to Merom, IN

grassland communities occur within the Wabash River corridor where most of the tilled fields abut directly on riparian forests. No attempt was made to determine the width of forested riparian borders because of constraints of time and funding.

The extent of bare banks and banks with a vegetated border consisting of only 1-2 trees is summarized in Table 2 and Figure 24. The location of these areas and the willow groves is shown in greater detail in Figure 25A-Q.

In 1994, 28.82 km (5.56%) of bare banks and 27.21 km (5.25%) of banks with only 1-2 trees were found within the 518 km of the middle Wabash River. These estimates are lower than 1983 figures which were 37.92 km (7.32%) bare banks and 35.0 km (6.76%) of areas with 1-2 trees.

The proportion of bare banks along the Wabash River in 1994 was highest in Reach 6 at the Cayuga Electric Generating Station (EGS) where virtually the entire outer bank of the large oxbow is bare. More than 9% of banks in Reach 12, the longest Reach extending from Darwin, Illinois to Merom, Indiana, were barren of woody growth (Figure 24). Other sections with relatively high percentages of bare banks included Reaches 2, 6, 7, 8, and 10.

The extent of banks protected minimally with only 1-2 trees in 1994 was greatest (9.77%) in Reach 11 from Terre Haute, Indiana to Darwin, Illinois. Reach 1 (Delphi, Indiana to Lafayette, Indiana) also contained many short sections with limited bank protection. In most other Reaches the proportion of banks with only 1-2 trees was less than the proportion of bare banks.

In 1994 we found many groves of small willows growing on banks which were bare or only thinly vegetated in 1983. Most were small patches, but some fairly extensive groves occurred in the following areas: (1) Clinton, Indiana, the mouth of Otter Creek, (2) the oxbow river bend south of I-70 at Terre Haute, and (3) the section upriver from York, Illinois. Some portion of the lower values found in 1994 compared to the 1983 data may be attributable to this pioneering invasion of willows. Another portion may be attributed to interpretive differences.

Riparian wetlands are important buffers of streams for sediment originating from disturbances such as road-building, logging, mining, building construction, and agriculture. The relationship is complex because of differences in topography, geologic material, soils, and climate, but

Table 2: Results of 1994 survey of eroding banks and banks with only 1-2 trees of the Wabash River from Delphi, Indiana to Merom, Indiana.

Reach	Total Bank Length (km)	Bare Bank (km)	Banks with 1-2 trees (km)	Bare + Banks w\ 1-2 trees (km) (%)
1	58	0.89	4.29	5.18 8.93%
2	30	1.90	1.59	3.50 11.65%
3	50	1.04	1.81	2.84 5.69%
4	54	2.96	1.52	4.48 8.30%
5	56	1.54	1.78	3.33 5.94%
6	16	2.46	0.75	3.20 20.02%
7	42	2.94	1.81	4.75 11.30%
8	46	3.04	1.66	4.70 10.22%
9	18	1.74	0.82	2.56 14.22%
10	32	2.17	0.72	2.89 9.04%
11	54	2.24	5.28	7.52 12.92%
12	81	7.33	5.18	12.51 15.44%
Totals	518 km	28.82 km	27.21 km	57.46 km 11.09%
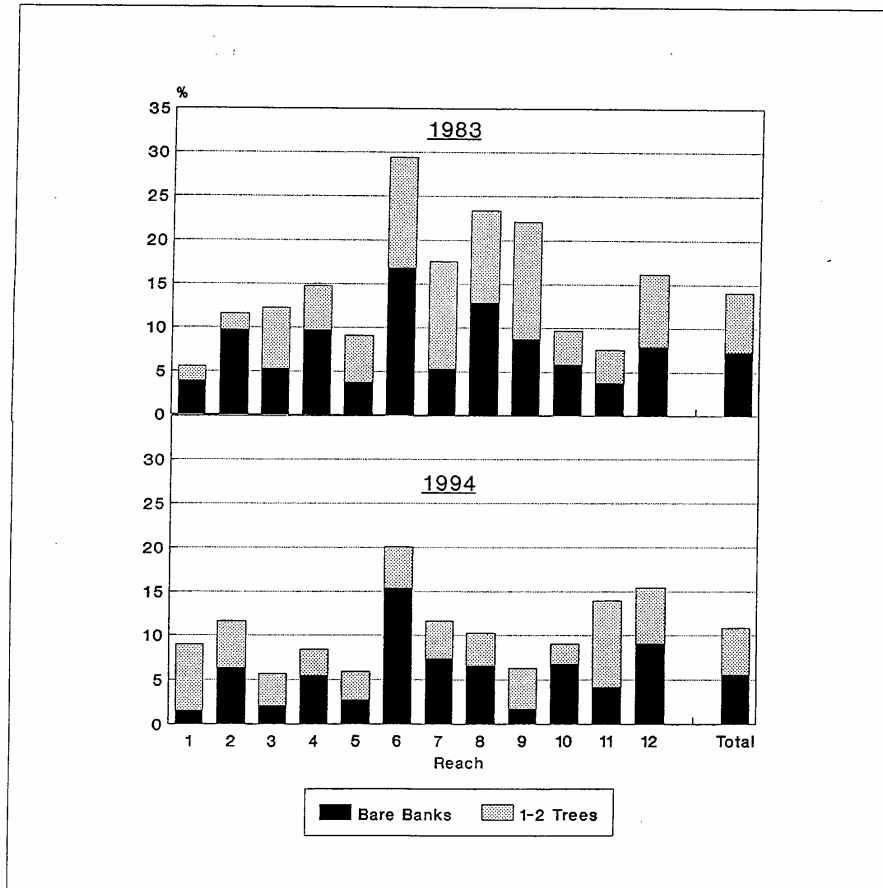
Figure 24: Percent bare banks and banks with only 1-2 trees between the edge of the Wabash River and agricultural fields in 1983 and 1994.

relatively narrow riparian buffer strips act effectively to remove a substantial portion of sediment carried by sheet erosion (Peterson and Correll, 1984; Kovacic et al., 1990; Osborne and Kovacic, 1993). The use of grassy waterways in field depressions to reduce soil erosion in cornbelt states is a familiar rural feature. Without an adequate riparian buffer sediment and nutrients readily move into rivers and their tributaries. Kovacic et al. (1990) and Osborne and Kovacic (1993) examined the effectiveness of such riparian wetlands in agricultural settings in Illinois. They found that a 16 m wide wooded corridor and a 39 m wide grassland absorbed 97% and 90% of nitrate-N, respectively, nutrients which would otherwise have entered a stream.

Riparian wetlands also trap sediments during flood events which otherwise would be deposited on agricultural fields. When floodwaters exceed bankful capacity most of the coarse suspended sediment is deposited within the strip of riparian forest close to the stream bank. In sections with no riparian forest, piles of coarse sand are deposited on agricultural fields rendering them unsuitable for the growth of typical crops. Condit and Roseboom (1989) concluded that stream channel erosion into floodplain rowcrop fields was the primary form of flood damage to landowners in the Court Creek, Illinois watershed.

Riparian wetlands also function to preserve bank stability. One characteristic of unregulated rivers and streams is a high degree of variability in discharge. During periods of flooding the roots and trunks of streambank trees absorb the grinding force of floating ice sheets, woody debris, and suspended sand and gravel which would otherwise erode or even relocate the stream

channel. In the lower 19 km (12 miles) of Sugar Creek more than 30 acres of cropland were eliminated over a 23 year period (1955-1978) through accelerated lateral erosion assisted by removal of riparian wetlands. Furthermore, during a wet summer the actively eroding banks were responsible for depressing the fish community (Gammon and Riggs, 1983).

The elimination of riparian wetlands along the middle Wabash River is clearly of major concern since approximately 5-7% of its banks are devoid of woody vegetation and another 5-7% provide a minimal buffer consisting of 1-2 trees between croplands and the river's edge. Furthermore, these minimal wetlands consist mostly of many short segments which could easily be undermined and subsequently induce a surge in the rate of lateral erosion. The ecological effects that eroding banks may exert on the Wabash River ecosystem is not known at the present time.

Inadequate riparian buffering of tributaries to the Wabash River also undoubtedly contributes to the oversupply of nutrients in the Wabash River mainstem. A recent study of the riparian condition of three Wabash River tributaries concluded that they were incapable of adequately protecting them from agricultural nonpoint source pollution (Gammon 1995).

As will be discussed in the next section, nitrate-N, ammonia-N, and phosphate concen-trations are all higher in the upper Wabash River than farther downriver, probably the result of extensive tiling of agricultural fields and channelization of tributaries in this area. The influence of this eutrophication on the entire Wabash River ecosystem will be discussed later.

A

B

Figure 25:
Eroding and near-eroding banks
bordering the middle Wabash
River from Delphi, Indiana to
Merom, Indiana in 1994.

	Eroding Banks
	1-2 trees
	Willow Groves

Delphi

Deer Creek

N

Tippecanoe River

Americus

I-65

Wildcat Creek

US-52

Lafayette

W. Lafayette

47

E

Big Pine Creek

Attica

Williamsport

F

Big Shawnee Creek

Fountain

Bear Creek

49

G

Discharge

Covington

I-74

H

Perrysville

Big Vermillion River

50

51

M

Terre Haute

N

Big Creek

Aurora Bend

Darwin

CHEMICAL ATTRIBUTES OF THE WABASH RIVER

In addition to the water which flows between its banks and the multitude of organisms living there, rivers also contain a large variety of dissolved inorganic and organic materials. It is not the intent here to thoroughly analyze these chemical attributes of the Wabash River. However, it is necessary to examine existing information for changes in water chemistry over time and differences in important chemical environmental factors from place to place.

The major modifications in the fish community which has been observed over the past decade are probably correlated with long-term changes in the chemical\physical environment. The character of the fish communities of the Wabash River differs from place to place. These differences might be associated with spatial variations in the physical/chemical environment.

The chemical environment of the river has been examined for a relatively long period of time. In April 1957 the Division of Sanitary Engineering, Indiana State Board of Health established 49 sites from which biweekly samples were collected for physical, chemical, and bacteriological analyses. Changes have been made over time in the location of collecting sites, in chemical procedures, and in frequency of sampling. In 1986 the Indiana Department of Environmental Management was formed and the Office of Water Management took over the program. The most recent report (1991) summarizes analyses from 103 stations throughout Indiana.

ORSANCO (1990) analyzed trends in data from 1977 to 1987 at multiple stations within the Ohio River basin from using the Seasonal Kendall Test. Records at 21 stations on the Ohio River mainstem and 12 stations on tributaries were examined, including the Wabash River at New Harmony, Indiana. A decrease in copper was the only statistically significant change noted at this station. Inadequate data existed for testing changes in total phosphorus, ammonia=N, NO_3/NO_2-N, total Kjeldahl-N, and total N. No statistical change occurred for total suspended solids, total dissolved solids, hardness, sulfate, phenolics, iron, lead, mercury, and zinc.

Martin and Crawford (1987), in addition to other records, examined data from eight water-quality stations of IDEM located on the Wabash River between Lafayette to Vincennes. They found that sulfate and suspended solids concentrations increased downriver. However, no spatial differences were noted for specific conductance, pH, or total alkalinity.

Table 1 summarizes water-quality data from the Ohio River Sanitation Commission (ORSANCO) (1990) study together with Indiana Department of Environmental Management (IDEM) data over the same time period. In addition to the IDEM and ORSANCO data, only a few other published chemical records are available for the Wabash River (Lesniak et al, 1973; Siefker and McCleary, 1979).

Table 3: Mean concentration and range of some physicochemical water-quality parameters for the period 1977-87[a] in different sections of the Wabash River.

Parameter	Huntington (rkm 658)	Peru (rkm 595)	Lafayette (rkm 502)	Montezuma (rkm 386)	Terre Haute (rkm 351)	Vincennes (rkm 209)	New Harmony[b] (rkm 83)
Total suspended solids (mg/L)	64.9 (5-1000)	66.2 (3-1260)	77.0 (3-1300)	113.7 (4-2430)	116.7 (7-2110)	112.8 (6-980)	157.2
Conductivity (umhos/cm)	597.6 (200-1160)	562.3 (280-1600)	533.4 (230-870)	595.7 (341-920)	562.2 (226-900)	552.0 (240-880)	488.7
Alkalinity[c] (mg/L as $CaCO_3$)	173.0 (90-275)	177.4 (116-258)	197.2 (117-270)	198.4 (122-276)	192.8 (90-260)	187.8 (112-252)	
Phosphate (mg/L)	0.217 (0.06-1.4)	0.182 (0.05-1.0)	0.170 (0.03-0.74)	0.202 (0.06-1.30)	0.207 (0.05-1.40)	0.204 (0.05-0.51)	0.300
Sulfate[d] (mg/L)	89.1 (21-230)	64.1 (21-100)	63.1 (28-90)	66.9 (30-90)	68.1 (31-100)	69.1 (28-120)	60.1
Ammonia (mg/L)	0.260 (0.1-0.2)	0.195 (0.1-1.8)	0.166 (0.1-1.3)	0.153 (0.1-1.0)	0.145 (0.1-1.8)	0.157 (0.1-1.0)	0.145
Nitrate (mg/L)	4.09 (0.1-15.0)	3.50 (0.5-8.9)	3.29 (0.2-10.1)	3.67 (0.1-10.6)	3.43 (0.1-9.0)	3.19 (0.1-7.4)	2.17
Organic Nitrogen (mg/L)			0.996		0.993	0.900	1.183
pH	7.65	7.72	7.80	7.81	7.77	7.86	

[a] Except where noted, data from Indiana Department of Environmental Management, Office of Water Management, Monitoring Station Records - Rivers and Streams. Published annually.

[b] ORSANCO. 1990. Long-term trends assessment of fifteen water quality parameters in the Ohio River. Toxic Substances Control Program, Ohio River Valley Water Sanitation Commission, Cincinnati, Ohio. 26 pp.

[c] 1986-90 only

[d] 1977-85 only

Conductivity

Conductivity is the ability of water to conduct an electric current. It is measured physically as the reciprocal of the electrical resistance of water expressed as umhos/cm. The electrical conductance of water depends upon the amount of dissolved anions and cations. Distilled water has a very low electrical conductance. The addition of charged particles makes the solution conductive although the variable mixture of chemicals in natural waters makes the relationship far from simple.

For any specific natural river there is generally a good linear relationship between electrical conductance and the dissolved solids concentration. The range of the slope constant for most rivers is generally between 0.55 and 0.75, although it may range up to 0.96 in some extreme cases (Hem, 1985). For rivers in the Ohio River basin including the Wabash River this relationship is described as:

Tot. Diss. Sol. = 0.625 x Cond.(umhos/cm)

Crawford & Mansue (1988) found that the specific conductance of the Wabash River averaged lower during summer (507-528 umhos/cm) than at other seasons (annual average 550-560 uS/cm). They noted no differences over space for either annual or summer conductance. They also found that total alkalinity was slightly lower during summer than it was for the entire year (annual alkalinity = 190-200; summer alkalinity = 180-190) and that there were no noticeable spatial differences.

In recent years the average conductivity or conductance varies only slightly along the Wabash River (Figure 26). The Ohio

River Sanitation Commission (ORSANCO) (1990) found lower conductance values at New Harmony than at most other stations and that changes over time were statistically insignificant.

Figure 27 illustrates annual averages for conductance from 1959 through 1989 at five stations sampled by the Indiana Department of Environmental Management (IDEM). It appears that conductance may have decreased at all stations during the 1980's and that over the period of record the conductance at the Peru station may have decreased most. However, this observation needs statistical verification.
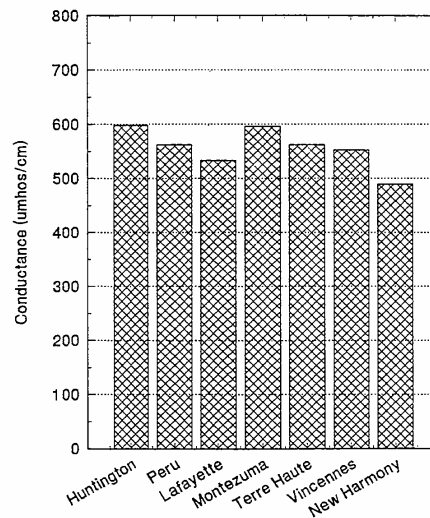
Figure 26: Mean conductivity of the Wabash River 1977 - 1987.
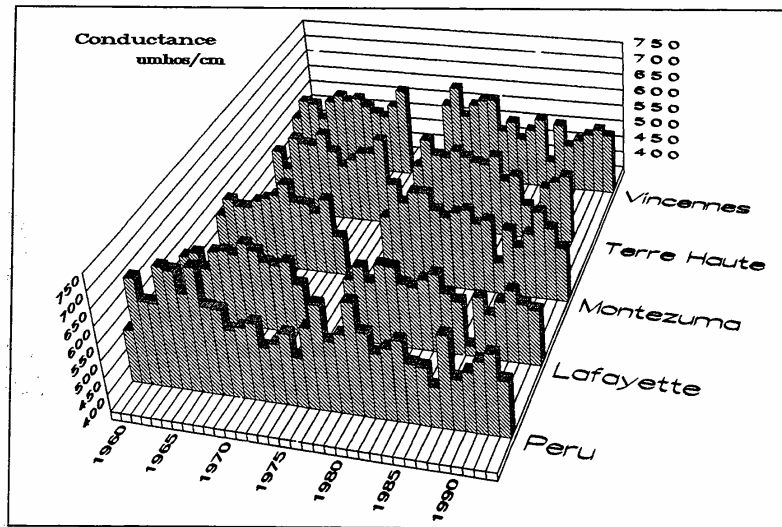
Figure 27: Mean annual specific conductance (umhos/cm)
of the Wabash River at five locations.

Nitrogen

The various chemical forms of nitrogen include elemental nitrogen, nitrates, nitrites, ammonia, and organic nitrogen. Elemental nitrogen (N_2) is slightly soluble in water. Maximum saturated concentrations of N_2 are about 15-20 ml/L during winter and 10-15 ml/L during summer (Wetzel, 1975). However, it is more concentrated in the hypolimnion of reservoirs and may become supersaturated when this water is released into spillways (Trefethen, 1972). Fish exposed to supersaturated N_2 may develop gas bubble disease and elevated mortality. Free-flowing waters such as the Wabash River would be saturated with N_2 at all times.

Nitrogen is an essential requirement for living organisms since it is a constituent of proteins and nucleoproteins. Atmospheric nitrogen may be fixed directly by blue-green algae, but most aquatic algae utilize inorganic nitrogen in the form of nitrates, nitrites, or ammonia. All of these forms of nitrogen are highly soluble in water.

Elemental nitrogen is added to water during denitrification when NO_3 is reduced to N_2. However, Owens and Nelson (1973) found denitrification rates in the Wabash River were very low and limited primarily by both high concentrations of dissolved oxygen and low temperatures during the winter months.

Ammonia (NH_4^+) and nitrites (NO_2.) are normally present in insignificant concentrations in surface waters except where industrial or organic sources of pollution enter. Ammonia nitrogen is important because it is potentially toxic to aquatic fauna at relatively low levels of concentration at high pH. It is produced mostly by bacterial deamination of

organic compounds and by hydrolysis of urea and, hence, is contained in effluents from wastewater treatment and various industrial plants. All aquatic fauna also generate ammonia, but usually diffusely and in negligible amounts.

The average concentration of ammonia ranges from 0.15 to 0.25 mg/L (Table 3 and Figure 28). The higher values in the upper Wabash River are probably the result of the more intensive agriculture and channelization found in the upper basin.

Ammonia is extensively applied as a fertilizer to agricultural lands during the spring and early summer, but it does not easily leach from soils because it adsorbs
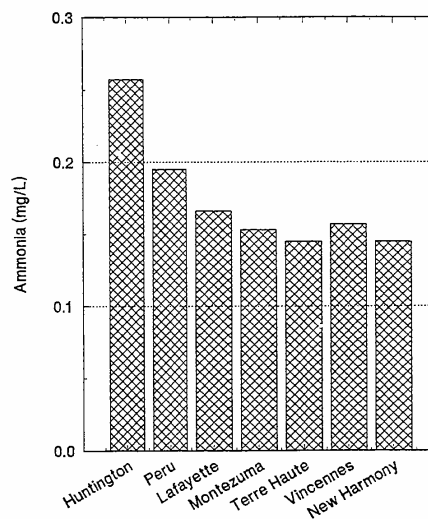
Figure 28: Mean ammonia concentrations (mg/l) of the Wabash River 1977 - 1987.

tightly to clay and other soil particles. Algae and some aquatic macrophytes can directly utilize ammonia as a source of nitrogen, but most ammonia is oxidized by specific bacteria to nitrite and nitrate. Active bacterial oxidation of ammonia probably occurs at specific sites within biofilms on and in bottom sediments or cooling towers. In most of the Wabash River these bacteria would probably be in a quiescent state (Lewis and Gattie, 1991).

Nitrite and nitrate concentrations together constitute total oxidized nitrogen. Nitrates are the primary essential nitrogen source for most aquatic flora and, together with phosphorus, are of great significance in eutrophication of lakes and streams. In most of the Wabash River the concentration of nitrites and nitrates averages 3.0 to 3.5 mg/L
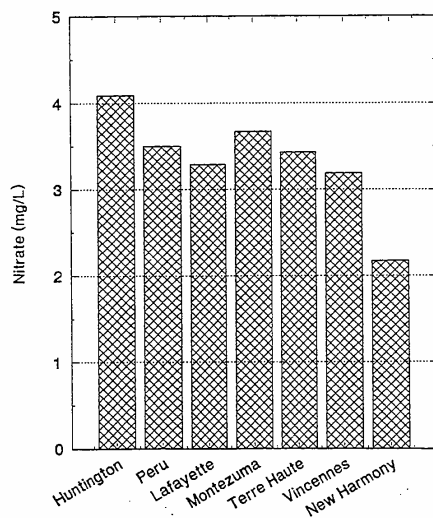
Figure 29: Mean nitrite + nitrate concentrations (mg/l) of the Wabash River 1977 - 1987.

(Figure 29). However, at New Harmony the concentration was only slightly greater than 2.0 mg/L (ORSANCO, 1990). As with ammonia, average nitrate-nitrite concentrations were highest in the upper basin at Huntington where it was more than 4.0 mg/L.

In addition to originating from the oxidation of ammonia, nitrites are generated by reduction of nitrates in wastewater treatment plants and by their direct use in industrial process water as a corrosion inhibitor. Nitrite is the actual etiologic agent of methemoglobinemia or "blue-baby syndrome" in infants and may also participate in the formation of carcinogenic compounds. Fortunately, nitrites usually occur only in low concentrations in natural river environments.

Nitrates, however, are seasonally abundant in agricultural areas where many small and medium-sized rivers may have nitrate concentrations exceeding 10 mg/l NO_3 (Hem 1985). Omernik (1977) found that nutrient concentrations were directly proportional to the percentage of land in agriculture and inversely proportional to the percentage of land in forest. With conventional farming practices an average of 140 pounds of nitrate fertilizer per acre is applied. Approximately 80 pounds will be taken up by corn while the remaining 60 pounds leaches into the soil water and eventually enters streams.

Nitrate concentrations in the lower Ohio River averaged between 3.2 and 3.9 mg/l between 1954 and 1961, but then increased during the next decade to as much as 7.7 mg/l. Average concentrations then declined to less than 5.0 mg/l between 1975 and 1979. These increases somewhat parallel the expansion of nitrogen fertilizer applica-

Organic nitrogen is defined as organically bound nitrogen. It includes such natural materials as proteins and peptides, nucleic acids and urea, and a variety of synthetic organic materials. It does not, however, include all organic nitrogen compounds. In practice, organic nitrogen and ammonia are determined together as "kjeldahl nitrogen" in which analysis such forms of nitrogen as azide, azine, azo, hydrazone, nitrate, nitrite, nitroso and others are not accounted for. Organic nitrogen of the Wabash River averages approximately 1.0 mg/l.

Flow-adjusted concentrations of ammonia-nitrogen, total Kjeldahl nitrogen, and total nitrogen throughout the Ohio River basin decreased from 1977 to 1987 (ORSAN-CO, 1990) possibly because of improved waste-water treatment. In 1978, for example, it was estimated that only 47% of waste-water treatment plants provided adequate treatment. By 1988 this figure had improved to 90%. However, levels of nitrate/nitrite nitrogen remained unchanged over this same period.

The Wabash River and surrounding terraine at Clinton, Indiana

Phosphorus

One of the most important chemical constituents of river water for aquatic organisms is phosphorus. It is required by every living cell (DNA, RNA, ATP, etc.). However-er, the various forms of inorganic phosphate generally are quite insoluble in water and, therefore, are limited in availability to those organisms. Phosphorus, among other required nutrients, is especially limiting to aquatic algae which absorb it avidly when it is present.

Phosphorus enters rivers through rainfall, dry fallout, erosional sediments, and anthropogenic sources such as sewage and industrial outfalls and, especially in agricultural areas, erosion from fertilized fields. Important chemical fractions of phosphorus include particulate-P, soluble-P, soluble "ortho" phosphate or PO_4-P, and total-P.

Most of the phosphorus in rivers is attached to particulate matter.

In 1971 the Indiana General Assembly enacted a Phosphate Detergent Law (IC 1971, 12-1-5.5) which banned the sale of laundry detergents containing more than 8.7% phosphorus by weight. This law was amended in 1972 to ban all phosphorus from detergents. A second amendment was passed in 1973 allowing the addition of trace amounts of phosphorus, less that 0.5% by weight. This legislation was prompted by recommendations of the International Joint Commission as part of an effort to ameleriorate eutrophication of the lower Great Lakes, especially Lake Erie. Since the ban on phosphate based detergents, the phosphorus concentration in Wabash River has decreased significantly (Figure 30).
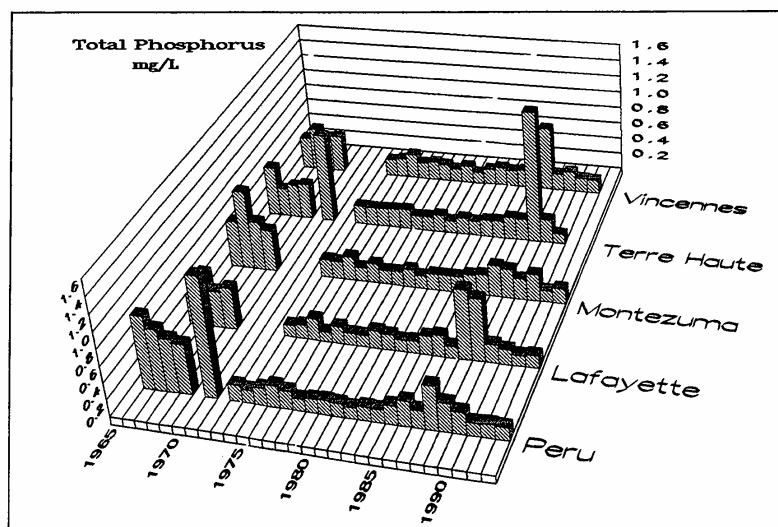
Figure 30: Mean phosphorus concentration (mg/L) of the Wabash River.

The actual magnitude of the decrease is somewhat difficult to assess because of changes in analytic procedures by the Indiana Department of Environmental Management (IDEM). Prior to 1971 only the dissolved phosphate concentration was measured. After that date the analytical methodology determined total-P.

Information about the changes in phosphorus loadings to rivers is included in the Indiana Stream Pollution Control Board's 305(b) Report (1977). A state-wide survey of phosphorus content of raw sewage indicated that overall concentrations of 10 -12 mg/l in 1971-72 declined to 7 mg/l or less by 1973-76. It was concluded that phosphorus loadings to streams were reduced by 25%-30% overall. Their Figure 50 indicates average phosphorus concentrations in the Wabash River of approximately 0 in1973, 0.25 mg/L in 1974 and 1975, and 0.32 mg/L in 1976.

The 1977 305(b) Report also cited the results of an NSF-funded study by the Department of Bionucleonics of Purdue University, which examined the status of phosphorus for the Wabash River at Lafayette. This study indicated phosphorus levels in the river were lower after the phosphate detergent ban (0.26 mg/L) than before (0.82 mg/L). It also concluded that agricultural runoff due to improper fertilizer application and heavy rainfall accounted for a large portion of total phosphorus present in the river.

The average concentration of phosphorus from 1977 to 1987 was similar from Peru to Vincennes, but considerably higher at New Harmony (Figure 31). This is somewhat surprising considering the close association of phosphates with suspended sediment which increased steadily downriver.
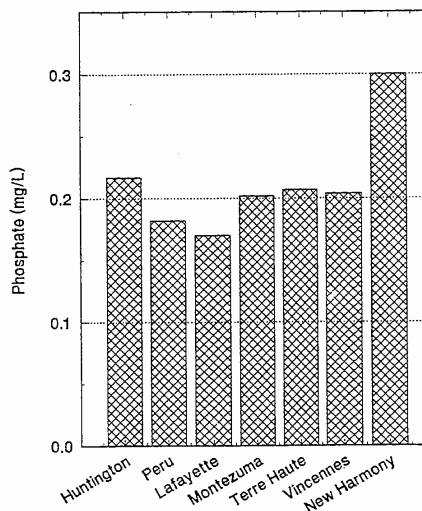
Figure 31: Mean phosphorus concentration (mg/L) of the Wabash River 1977 - 1987.

Smith et al. (1987) found a strong statistical association ($p < 0.001$) between phosphorus trends and trends in suspended sediment. Phosphorus increases were found to be associated with high values of fertilized cropland ($p = 0.103$) and density of cattle ($p = 0.002$).

Phosphorus concentrations in Indiana rivers are far higher than in "natural" waters despite recent actions. Meybeck (1982) estimated that naturally occurring dissolved inorganic phosphate in river water should average only about 10 ug/L as P with perhaps an additional 15 ug/L as dissolved organic phosphate. He also noted that about 95% of the phosphorus carried in river water is in particulate form. His estimates indicate that human activities increase phosphorus concentrations in European and North American rivers ten- to one-hundred-fold.

Dissolved Oxygen, BOD, and DOD

The amount of dissolved oxygen (DO) in any freshwater ecosystem is arguably the single most important chemical determinant of the character of that ecosystem. Most microorganisms and all animals require an external source of oxygen for life processes. Plants also require oxygen, but they create their own supply if light is available in sufficient intensity and duration and need an external source of oxygen only under dark conditions.

Oxygen solubility in pure water is determined primarily by temperature and secondarily by atmospheric pressure and other factors (Figure 32). Over the normal range of temperatures experienced by organisms in our rivers and streams twice as much oxygen is available at 0 °C as at 34 °C. Regardless of temperature, however, concentrations of dissolved oxygen in water are miniscule compared to the amount available to air-breathers such as ourselves. Whereas about 20.95% of the air we breath consists of oxygen, most aquatic organisms thrive in water with dissolved oxygen concentrations of only 5 to 15 mg/L or 0.005% to 0.015%. Their morphological and physiological adaptations to this scarcity of dissolved oxygen are marvelously efficient and the product of millions of years of adaptation.

The actual dissolved oxygen concentration in streams and rivers is dependent upon the physical characteristics of the stream, the nature and intensity of in-stream chemical reactions, and the biological activities of the aquatic community. The influence of near-stream terrestrial activities is of much greater importance for streams and river than it is for lakes.
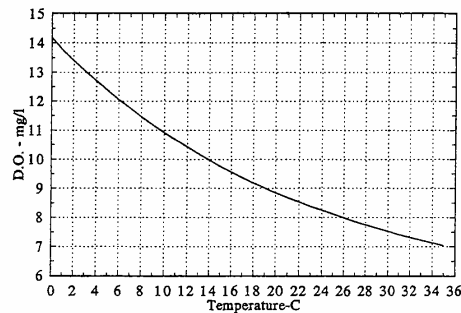
Figure 32: The relationship of dissolved oxygen concentration (mg/L) at saturation to temperature (°C).

A general model of important determinants of dissolved oxygen in the Wabash River is shown in Figure 33. Major contributions of oxygen to river water are made by incorporating atmospheric oxygen through the water surface - reaeration - and by the generation of excess oxygen resulting from photosynthesis of aquatic plants. Major routes of oxygen removal include, in addition to nonphotosynthesizing aquatic plants, the oxidation of reduced compounds such as ammonia and ferrous iron, aerobic decomposition of dissolved and particulate organic compounds (carbonaceous BOD), aerobic decomposition of reduced compounds, organic compounds, and the benthic fauna comprising the bottom substrate (benthic demand), and uptake to satisfy the metabolic needs of all animals in the water column. The removal of oxygen by fish and zooplankton is relatively insignificant compared to other avenues of uptake and is usually not even considered.
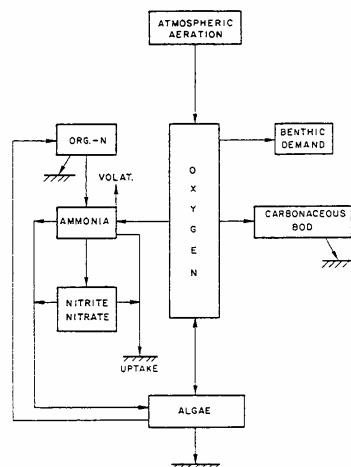
Figure 33: Dissolved oxygen model for the middle Wabash River. (after HydroQual, 1984)

The annual pattern of the average dissolved oxygen concentration in the Wabash River is the reverse of the temperature curve, ie. it is higher during the winter and lower during the summer.

There are two major reasons for this. Firstly, there is an inverse relationship between water temperature and dissolved oxygen concentration at saturation which has just been discussed. Secondly, the relatively low average dissolved oxygen concentration during summer and early fall is caused by the increased metabolism of a larger biomass of aquatic biota, especially phytoplankton and benthic macroinvertebrates which are most abundant and more concentrated during this period of the year. Furthermore, all of these organisms are at their metabolic maxima because of the relatively high temperatures. The dissolved oxygen concentration often exhibits great diurnal variability especially during the summer (Figure 34).

Much has been made of the ability of rivers and streams to "self-purify" when they receive a load of organic matter. Most of the organic material entering smaller midwestern streams shaded by natural riparian vegetation is in the form of leaves, bark, bud scales, etc. either by direct leaf-fall or as "leaf wads" washed in during rain storm events (Bird and Kaushik, 1981). The stream organisms, benthic macroinvertebrates in particular, are well adapted to take advantage of this annual gift of energy, known ecologically as coarse particulate organic matter (CPOM) (Williams 1981). After repeated processing larger rivers such as the Wabash River eventually receive the residue in the form of fine particulate organic matter (FPOM) and any nutrients released during decomposition (Cummins et al. 1983).

Streams influenced minimally by man's activities may at times be overwhelmed by the autumnal load of leaves which reduces dissolved oxygen concentration and turns water black (Slack 1955, Schneller 1955).
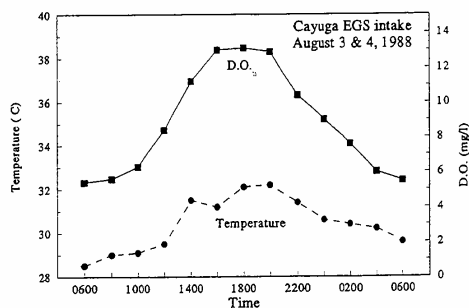
Figure 34: Typical diurnal change in dissolved oxygen and temperature in the Wabash River.

With most of the world's expanding human population located near freshwater, anthropogenic sources of CPOM and FPOM have become more important than natural sources. The combined organic contributions of industry, agriculture, and treated or untreated human wastes are now of far greater importance than natural sources. Furthermore, they are released into streams more or less continuously throughout the year. Regardless of origin, all of this material together with microorganisms and phytoplankton, imposes on a river a Biochemical or Biological Oxygen Demand (BOD).

BOD is a heterogeneous collection of large and small molecules and particulates together with attached microorganisms and living phytoplankton. Some of the simpler compounds are quickly oxidized to a stable chemical form, while others require the cooperative work of microorganisms and the aquatic fauna over a long period of time. In this country the BOD is determined by measuring the loss of DO in a water sample incubated at 20 °C in the dark over a 5-day

period and expressing the result in milligrams of oxygen per liter. In some countries a 7-day incubation period is used. In addition, an "ultimate" BOD value is often estimated.

A major effort to reduce point sources of BOD was undertaken during the past 20 years. In the decade following passage of the Clean Water Act of 1972 it was estimated that municipal BOD loads had decreased by 46% and industrial BOD loads had decreased at least 71% (U.S. Environmental Protection Agency, 1982). Significant progress in reducing industrial sources of BOD was made in the mid- to late-1970's. Funding for upgrading municipal waste treatment facilities through the EPA's Construction Grants Program also increased during this period and reached their highest levels in 1979 and 1980 (Congressional Budget Office, 1984).

The sources of carbonaceous biological oxygen demand (CBOD) entering the middle Wabash River were determined by HydroQual (1984) during August of 1981 and 1982 (Figure 35). Direct contributions from
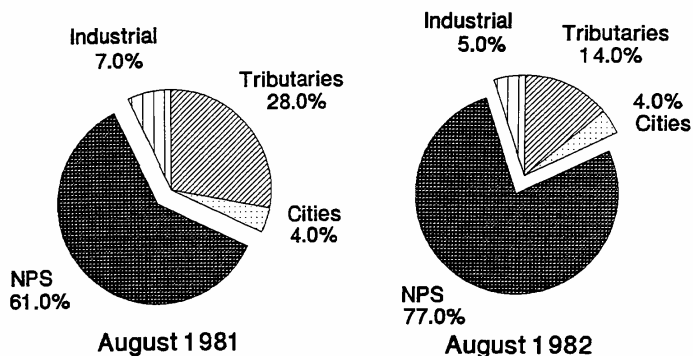
Figure 35: Sources of carbonaceous BOD for the middle Wabash River.
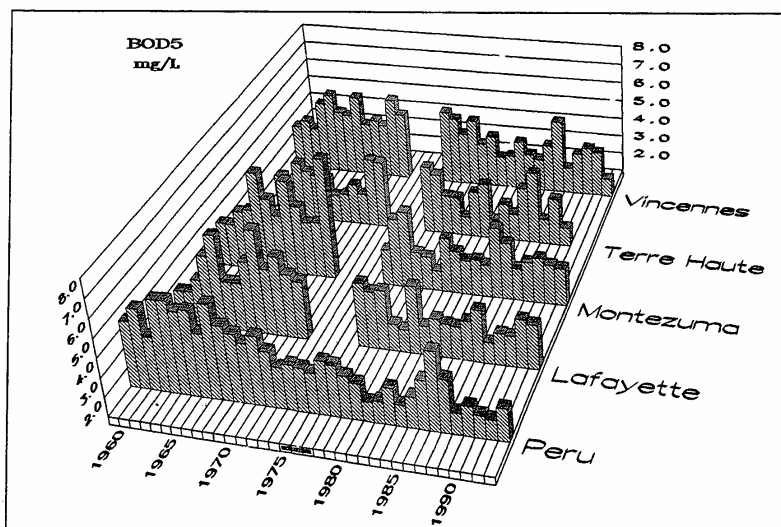
Figure 36: Mean annual BOD (mg/L) of the Wabash River
from 1961 through 1993.

industries and municipalities were estimated individually at 220 to 4400 kilograms per day (100 to 2000 pounds per day) and collectively constituted approximately 10% of the total load. The major tributaries were estimated to contribute an additional 15-30%, although it should be pointed out that this CBOD originates from varying sources. Big Vermilion River, alone, contributed approximately 16,500 kg/day (7500 lbs/day), a loading roughly equivalent to all of the other major tributaries combined.

That fraction of carbonaceous biological oxygen demand which entered the river diffusely was determined by subtracting the point-source loadings from the estimated total CBOD. This was found to comprise 60% to 77% of the total CBOD and was estimated to be 136,000 to over 200,000 kg/day (62,000 - 92,000 lbs/day). It is likely

that most of this substantial contribution is of nonpoint agricultural derivation, although part of it may have originated *in situ* as phytoplankton.

In addition, it was estimated that 100,000 - 130,000 kg CBOD/day (47,000 - 58,000 lbs/day) flowed in from the upper Wabash River. No sources of origin were identified and HydroQual categorized this as a "point" source contribution for modelling purposes. However, it is likely that two-thirds to three-quarters of this amount was derived from agriculture.

In the decade of the 1970's there was a sharp decline in the mean annual BOD of the river (Figure 36). Since then levels appear to have stabilized at about 2.5 to 3.0 mg/l in the 1980's. BOD levels averaged 4.5 to 5.0 mg/l over most of the length of the
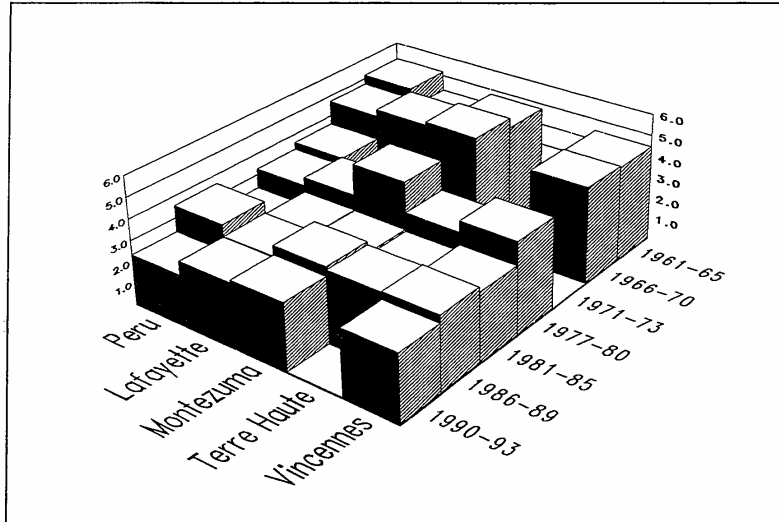
Figure 37: Five-year mean BOD (mg/L) at five locations on the Wabash River.

river during the 1960's (Figure 35). There-fore, the national effort to reduce CBOD no doubt included the Wabash River Valley and that may be the major cause for observed reductions of BOD in the Wabash River. Steady improvements in waste treatment were made at Terre Haute, Lafayette, Covin-gton, Kokomo, Frankfort, and most other sizeable communities in the watershed (Ano-nymous, 1983).

These declining values of the average annual BOD provide encouraging evidence for the efficacy of improving treatment of industrial and municipal wastes. However, when the annual pattern of BOD is examined (Table 4 and Figure 38) it is apparent that today's BOD levels are lower only during part of the year. Biological oxygen demand

levels during the months of July, August, and September, the months of lowest flow, are as high or higher than ever. Although there has been a reduction in BOD originating from industries and municipalities, the favorable temperatures and ample nutrient levels during summer and early fall permit the development of large densities of phytoplank-ton, an important fraction of the total BOD load. As will be shown later, densities of phytoplankton are particularly high in July, August, and September.

The importance of BOD to both aquatic organisms and the aquatic ecosystem as a whole is no doubt significant, but it is difficult to categorize and evaluate. On the one hand, part of the BOD is food and energy for aquatic biota. On the other hand,

Table 4: Mean and standard error of monthly BOD of the Wabash River at Lafayette.

Month	1961 - 1969	1970 - 1979	1980 - 1989	1990 - 1993
January	4.01 (0.579)	5.15 (2.958)	1.64 (0.341)	1.20 (-)
February	3.48 (0.515)	4.00 (0.819)	1.70 (0.363)	2.70 (-)
March	4.23 (0.949)	5.72 (1.996)	2.12 (0.434)	2.00 (-)
April	4.47 (0.647)	4.02 (0.676)	2.61 (0.472)	2.67 (0.306)
May	4.98 (0.322)	4.01 (0.443)	2.80 (0.554)	-
June	5.71 (1.392)	4.64 (0.628)	2.58 (0.374)	3.65 (2.540)
July	5.56 (0.750)	4.56 (1.044)	4.74 (1.705)	-
August	5.77 (0.534)	4.20 (0.651)	6.19 (1.254)	4.85 (0.071)
September	5.42 (0.474)	4.44 (1.000)	4.06 (1.001)	2.00 (-)
October	4.92 (1.089)	3.16 (0.450)	1.91 (0.356)	2.30 (0.141)
November	3.22 (0.473)	2.58 (0.542)	1.76 (0.334)	1.00 (-)
December	3.62 (0.916)	2.86 (0.558)	2.14 (0.232)	3.15 (0.495)
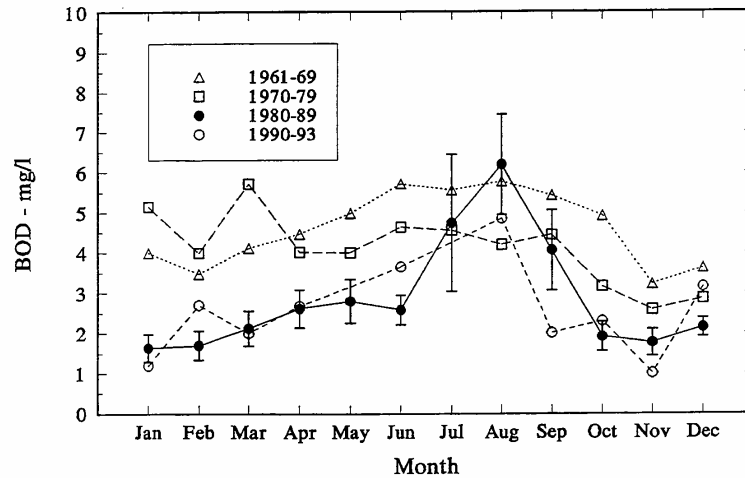
Figure 38: Annual pattern of BOD (mg/L) at Lafayette, Indiana during the decades of the 1960's, 1970's, 1980's, and 1990's.

particulate BOD contributes toward increasing turbidity to the detriment of species of fish which locate food visually. It may also physically smother spawning and nursery areas. Its greatest impact, however, probably lies in its influence on the dissolved oxygen concentration of the water which, in turn, affects the aquatic fauna.

One way of characterizing the DO status of a river is to estimate the dissolved oxygen deficit (DOD) at different rates of river discharge by computer modeling. The DOD is the saturation DO concentration at the prevailing temperature minus the actual DO concentration (Smith et al. 1987). A DOD model for the Wabash River was developed by HydroQual (1984) using a version of the DIURNAL computer model and data collected in 1981 and 1982. At low discharge rates this model projected values of 2.0 to 2.5 milligrams of oxygen per liter from Delphi to Montezuma (Figure 39). Dissolved oxygen deficit levels then increased sharply to reach a value of about 4.0 mg/L from Terre Haute to Merom, Indiana.

Phytoplankton respiration accounted for the largest single uptake of dissolved oxygen, an estimated 50-60% of the DOD in the upper reaches and about 70% downriver from Terre Haute. The second largest source was carbonaceous biological oxygen demand (CBOD) which entered the river from multiple point sources and accounted for about 10% of the DOD in the upper reaches and over 15% downriver from Terre Haute. Sediment oxygen demand (SOD) was estimated to be the third largest oxygen sink. Nitrogenous BOD and other sinks also contributed to a minor degree.

Smith et al. (1987) found no significant relationship between the change in BOD loads from municipal treatment plants within 160 km upstream from U.S.G.S. NASQAN stations and the decline in the dissolved oxygen deficit. Most NASQAN stations are located on large rivers. If DOD is mainly caused by respiring algae, as in the Wabash River, then improvements in DOD due to decreased point loadings of BOD might well be obscured.
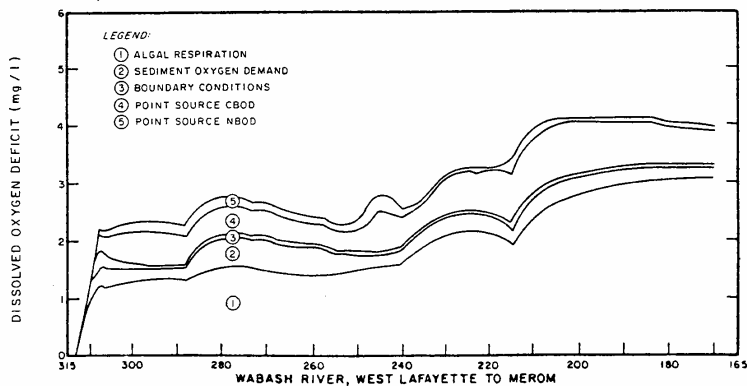
Figure 39: Estimated mean dissolved oxygen deficit (DOD) for the middle Wabash River during low-flow conditions. (After Figure 6.17(A), HydroQual, 1984)

Heavy Metals

It is difficult to assess the temporal and spatial differences of many heavy metals because the sampling effort and locations have changed. As previously mentioned, copper concentrations decreased statistically over the period 1977 - 1987 at New Harmony (ORSANCO 1990), as it also did elsewhere within the Ohio River basin.

Table 5 summarizes data from the ORSANCO study (1990) and unpublished data from the Indiana Department of Environmental Management. Concentrations of iron, lead, manganese, nickel, arsenic, and copper are higher at downriver stations than upriver.

Table 5: Mean concentration (ug/l) of metallic elements in the Wabash River. Concentrations are total and for the period 1981 - 1987, except where noted.

Metals	Laf.	T.H.	Breed	Vinc.	N.Har.[a]
Arsenic	2.13	2.49	2.59	2.47	-
Berylium	2.00	2.00	-	-	-
Cadmium	-	2.13	2.00	-	-
Chromium (Hex)	10.00	10.00	9.85	10.00	-
Chromium	11.67	12.04	11.62	10.89	-
Copper	6.78[b]	7.07[b]	7.90	-	17.77
Iron	2,195[b]	3,754[b]	4,328	-	4,613
Lead	12.03[b]	13.36[b]	9.18	-	28.54
Manganese	122.0	209.3	223.4	-	-
Thallium	20.00	20.00	-	-	-
Nickel	6.47	8.12	8.23	-	-
Zinc	23.98[b]	23.01[b]	-	-	-
Antimony	0.80	0.60	-	-	-
Selenium	1.15	1.24	-	-	-
Mercury	0.12[b]	0.10[b]	-	-	0.32

[a] 1977 - 1987
[b] 1981 - 1987

The concentration of metals in the Wabash River is related not only to industrial sources, but also to the coal mining industry. Coal deposits have been found in 20 counties in southwestern Indiana. The influence of coal mining, past and present, extends northward only to the level of the Big Vermilion River at Rkm 414 (RM 257).

Underground mines produced most of the coal from the late 1800's until about 1950 after which strip mining predominated. Not until the passage of the Indiana Strip Mine Law in 1968 was there any serious attempt to reduce mining effects. This act required that all acidic material be buried and that all stripped lands be graded and seeded. However, the law applied only to active mined areas and not to older abandoned mines which continue to leach acids and heavy metals into surface waters (Thomas 1978, 1981).

Several studies have examined the effects of coal mining on water quality in streams of southwestern Indiana (Corbett and Agnew 1968; Corbett 1969; Wilber et al. 1980; Peters 1981; Wangsness 1982; Wangsness et al. 1981a, 1981b, 1983; Zogorski et al. 1981; and Martin and Crawford 1987). Generally these investigations indicate that specific conductance, dissolved solids, acidity, sulfate, iron, manganese, and aluminum were higher in streams draining mined areas than in streams in unmined areas. Total alkalinity and pH were generally lower in waters in mined areas than in unmined areas.

A few older abandoned mining areas are located directly adjacent to the Wabash River mainstem, but most active and abandoned mines are located near its tributaries. The products of these mines enter tributary waters which eventually empty into the Wabash River. Big Vermilion River is the largest tributary affected by mining. Others proceeding sequentially in a downriver direction include Coal Creek, Brouillettes Creek, Otter Creek, Coal Creek, Little Sugar Creek, and Honey Creek.

Thomas (1978, 1981) assessed impacts of abandoned mines in west-central Indiana and recognized three priority classes. Six mine sites were included as Priority I, the most serious. Thirteen more mines were classified as Priority II, somewhat less serious. Ten more mines which contributed only small amounts of pollutants were designated as Priority III. An additional category, IV, represented areas which were not polluting streams or lakes.

The remains of the so-called "Green Valley Mine" near Little Sugar Creek illustrates the problems presented by old mines. This deep mine was located immediately east of the Illinois state line and about eight miles northwest of Terre Haute. It began production of coal in 1947 and was abandoned in 1963. Gob piles and slurry formerly covered over 100 acres, an ugly pile of barrens devoid of vegetation and capped by a small acidic pond.

Acid runoff passed into West Little Sugar Creek and then on to the Wabash River. Frequently the upper stream was milky white and the water near the Wabash River red-orange in color. Thomas (1978) examined water quality from September through mid-November, 1977 and found that the pH was frequently less than 3.0 with conductivity which was often greater than 2000 umhos/cm (Table 6). Heavy metal concentrations were apparently substantial for many decades.

Table 6: Water quality of West Little Sugar Creek near the Green Valley mine, September to mid-November, 1977.

Water Quality Parameter	Number of Samples	Median Concentration*	Range*
Conductivity (umhos)	8	2,289	937 - 6,254
pH	8	4.31	2.87 - 5.96
Arsenic	13	50.9	29.3 - 641.0
Barium	13	85.9	32.5 - 122.0
Cadmium	12	2.68	1.88 - 23.70
Chromium	13	94.6	7.28 - 517.0
Iron	15	387,000	120,000 - 6,070,000
Lead	6	7.63	5.13 - 30.40
Manganese	15	4,650	1,100 - 31,000
Nickel	6	255	201 - 1,030

* ug/l except for conductivity

The Indiana DNR Abandoned Mine Program has been working to correct some of the water quality problems caused by abandoned mines. Biological assessment of Little Sugar Creek indicated that formerly there was no aquatic life for at least four miles downstream (T. Sellers, IDNR, personal communication).

The Green Valley Reclamation Project was completed in November 1994 after two years effort and an expenditure of nearly $2.5 million. Vegetation has now been established on over 100 acres of previously barren refuse. The pH of runoff from the site now exceeds 7.0 and total suspended solids and total iron have been dramatically reduced.

The rehabilitation of what has been characterized as the largest and most environmentally devastating abandoned mine sites in Indiana cannot but help improve water quality in the Wabash River downriver from Terre Haute, Indiana. Nevertheless, the aggregate contributions of all the active and abandoned mines within the Wabash River basin should be assessed in greater detail. As will be shown later, the fish community of the middle Wabash River changes quite suddenly very close to the northern extent of mining areas.

THE FISH COMMUNITY OF THE WABASH RIVER

The Wabash River mainstem may be divided arbitrarily into the headwaters upriver from Huntington Reservoir (rkm 660) (RM 410), the middle mainstem extending from the Huntington dam south to the mouth of the White River (rkm 206 to 660) (RM 130 to 410), and the lower mainstem from White River to the Ohio River.

The fish community of the Wabash River has received the attention which it deserves only in recent decades. The 1911-12 Biennial Report of the Commissioner of Fisheries and Game of Indiana (1913) stated that in the Wabash River from the Terre Haute area ". . **up to Huntington, and beyond, there are many splendid bass fishing places. But as a fishing stream, where one would choose to go to enjoy all the beauties of nature, most people prefer its neighbor and tributary the Tippecanoe, a few miles to the north."**

Regular collections of fish from the mainstem of the lower Wabash River have been made primarily by Illinois Department of Conservation personnel. This data is currently being summarized at the present time (Day, personal communication).

Indiana Department of Natural Resources studies of the Upper Wabash River

Indiana Department of Natural Resources studies of the upper Wabash River indicate that, while a variety of other species are present in small numbers, gizzard shad, carp, and carpsucker species constituted over 55% of numbers and 65% of biomass of fishes in the river above Huntington Reservoir (Pearson 1975). This section of

river is sluggish and ditch-like, with the surrounding landscape dominated by an extensive rowcrop agriculture. The mainstem and its tributaries are used primarily for the removal of excess water during the spring rainy period.

In 1989 Braun (1990) electrofished 18 stations from the Indiana-Ohio state line at rkm 746 (RM463) to Peru, Indiana at rkm 590 (RM366) and, upstream of Huntington Dam, found a **"mediocre"** fish population dominated by carp and white suckers. Catches of sauger were lower than in 1974, but walleye, which were first stocked into upper Wabash reservoirs in the early 1970's, had increased. Shovelnose sturgeon and spotted bass had extended their ranges northward during the intervening period.

After flowing through Huntington Reservoir the turbidity of the river is reduced and environmental conditions and the quality of the fish community improve considerably below the Huntington dam. Assisting in the process are the Salamonie and Mississinewa rivers, both of which pass through reservoirs before entering the Wabash mainstem.

Here **"the river retains much of its native beauty"** although algal densities sometimes color the river brownish and produce high mid-afternoon DO concentrations (Robertson 1975). The fish community between Huntington dam (rkm 658 = RM410) and Covington, Indiana (rkm 436 = RM 271) was dominated by gizzard shad, carp, and carpsuckers (58% by numbers, 56.6% by weight), but redhorse and game fish (drum, sauger, and smallmouth bass) were much more abundant.

Fish Studies of the middle Wabash River
by DePauw University

The fish communities of the middle Wabash River have been studied since 1967. Most collections of fish from 1967 to 1973 were concentrated in the immediate vicinity of the Wabash Electric Generating Station (EGS) located north of Terre Haute, Indiana and the Cayuga EGS which began operating in the fall of 1970. During this period we experimented extensively to discover the most effective and efficient collecting methodologies. Hoop nets, D-nets, gill nets, A.C. electrofishing, and D.C. electrofishing were examined. The least selective and most versatile sampling apparatus proved to be D.C. electrofishing using a Smith-Root Type VI electrofisher and this has been employed as the standard since 1972 (Gammon 1973).

Initially seines were not used because of a scarcity of suitable habitat in the vicinity of the electric generating stations. In most areas the water depth increases rapidly from shore and the near-shore bottom substrate usually consists of a soft mixture of sand and mud. Log jams are also common throughout the river. During some years it was impossible to seine even suitable habitat because of high summer discharge.

Seegert (personal communication) has argued that a seining component should be included in the Wabash River sampling program because smaller fish species such as darters and minnows are otherwise omitted. Routine seining collections were included as components in 1977 and special seining studies have also been made from time to time. New species of fish were found by seining, however, they did not clarify environmental assessments beyond that shown by the electrofishing collections alone

since most seining sites were located at the mouths of tributaries. During high-flow summers it was virtually impossible to find suitable seining sites anywhere. We have included a seining component in studies of smaller streams, but have not found it of value for the Wabash River itself.

During this early period we found that catches of fish in the range of habitats available in the Wabash River differed qualitatively and quantitatively (Gammon 1976). The strong probability that environmental factors other than heated water were operating to influence the fish community also became evident.

In 1973 we began systematic collections over 100 miles of river between Independence, Indiana and Terre Haute, Indiana and extended it to greater distances both up-river and down- over the next few years. Based upon early preoperational studies at the Cayuga Electric Generating Station most collecting stations were sited in relatively fast-water sections of river having good cover and an average depth of one meter or less. These were often, but not always, on the outside of river bends. These sites usually harboured a greater variety of species and yielded larger catch rates than either deeper water sites or the slow shallows of the inside river bends.

A total of 63 collecting stations were regularly sampled between Delphi, Indiana and Merom, Indiana. Eight of these stations were concentrated in the area of the Cayuga Electric Generating Station and another five stations were concentrated above and below the Wabash Electric Generating Station.

The remaining stations were sprinkled throughout the river with greater densities at population centers of Lafayette, Indiana and Terre Haute, Indiana.

Originally each collecting station consisted of a variably long section of shoreline, but after 1975 each station consisted of a 0.5-km section of shoreline as measured with a Leitz optical rangefinder.

Our monitoring objective was to execute three electrofishing passes at each of these regular collecting stations each summer. An ideal series of collections began at Delphi, Indiana and concluded four to five days later at Merom, Indiana or Hutsonville, Illinois. However, during some years only two passes or less were possible because of unusually high discharge which negatively influenced collecting efficiency in some if not all sections of the river. Weather and flow conditions often necessitated an adaptation of the collections to shorter sections of river. In some years it was possible to conduct a fourth sampling effort. During summer, 1988

the problem was often finding water which was sufficiently deep in which to collect.

For analytic purposes the river was divided into 12 Reaches as indicated in Table 7 and shown in Figure 40, with each Reach containing at least five collecting stations. Although eight stations were located at the Cayuga Electric Generating Station, only five stations having the desired physical characteristics were included in the overall analysis. At the Wabash Electric Generating Station two of the five stations were ambient and unheated. Therefore, determinations of the community parameters and the individual species abundances were based upon approximately 3 collections at each of 5 locations within each Reach or a total of 15 samples each summer.

Each collecting station was sampled near shore with a Smith-Root Type VI electrofisher producing 600 VDC and 60 pps. Pulsed DC current flowed into an electrode system consisting of two circlets of short stainless steel anodes suspended at the water

Table 7: Location of the study Reaches of the middle Wabash River.

Reach	River Mile (Rkm)	Description of Location
1	330 to 313 (531-502)	Delphi to north Lafayette, Ind.
2	312 to 302 (501-486)	Lafayette & W. Lafayette area
3	301 to 286 (485-460)	Lafayette to Attica, Ind.
4	285 to 269 (459-433)	Attica to Covington, Ind.
5	268 to 251 (432-404)	Covington to Coal Creek
6	249.6 (402)	Cayuga Elec. Generating Station
7	247 to 233 (396-375)	Cayuga EGS to E. Lilly, Clinton
8	232 to 218 (374-351)	E.Lilly, Clinton to Otter Creek
9	215.4 (347)	Wabash Elec. Generating Station
10	213 to 203 (343-327)	Terre Haute, Ind. area
11	202 to 186 (325-299)	Terre Haute STP to Darwin, Ill.
12	185 to 160 (298-257)	Darwin, IL to Merom, IN
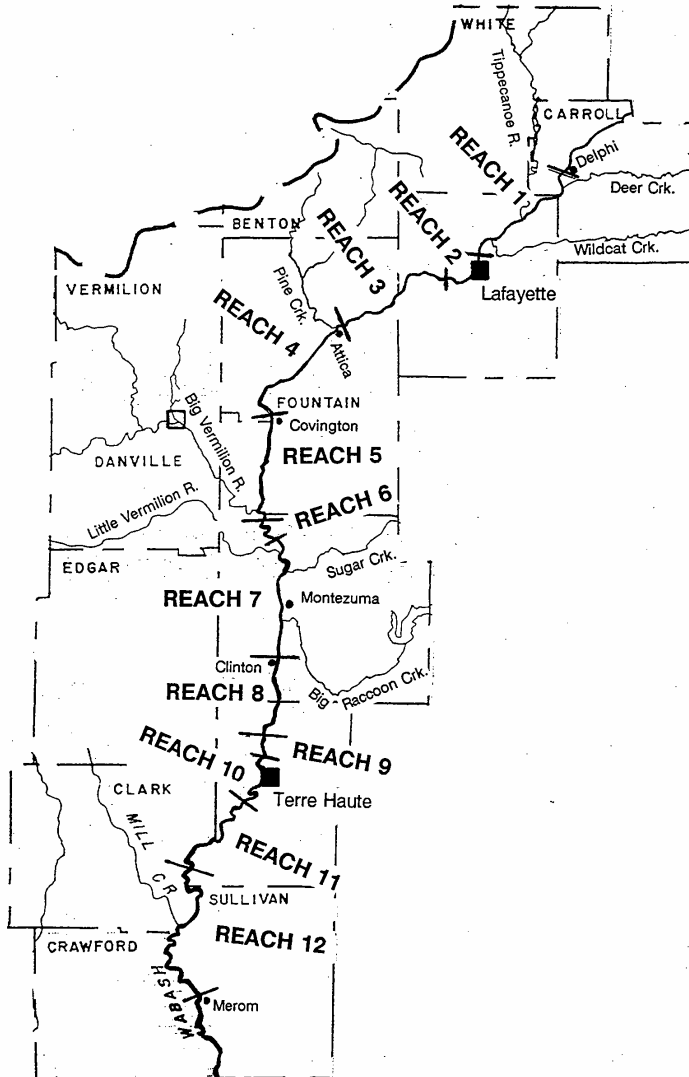
Figure 40: Locations of 12 collecting Reaches in relation to major streams and population centers.

surface by bow booms and two gangs of long woven copper cathodes off the port and starboard gunwales. A single netter worked from the bow of the boat using a long-handled dip net having one-quarter inch square mesh netting. All captured fish were placed in a holding tank and processed after the entire collecting station had been electrofished. Fish were identified to species, weighed, measured, and returned to the river unharmed as soon as possible.

All data were entered into a computer data base and processed by a battery of analytic programs which were developed in-house and modified over time by a generation of students and DePauw Computer Center personnel. The data program permits the entry of some physical and chemical parameters as well as biological attributes. Output options include summarizations of the catch data for each species, calculations of community parameters, and length frequency and condition factor analysis.

Two measures of abundance of the fish community included the following:
(1) numbers per unit collecting effort, which in this study is the number of fish captured per kilometer of shoreline electrofished, and (2) biomass per unit collecting effort or kilograms of fish captured per kilometer.

Three measures of diversity were derived including: (1) the mean number of species captured per collection, (2) the Shannon-Weaver or Shannon-Weiner index of diversity or heterogeneity based on numbers of each species captured per collection using natural logarithms (H'), and (3) the Shannon-Weiner index based upon weight of each species using natural logarithms.

Equitability of species abundance in each electro-fishing collection was derived from the S-W index values as $J = H'/H'_{max}$.

Early in the study it was observed that all of these measures of community, except equitability, exhibited the same basic pattern over space. Therefore, a Composite Index of Well-Being (Iwb)- was constructed, which appeared to best represent the catches in terms of both diversity and abundance (Gammon 1980). The composite "Index of Well-Being" (Iwb) was calculated as:

$$Iwb = 0.5 \ lnN + 0.5 \ lnW + Div(no) + Div(wt)$$

where

N = number of fish captured per km
W = weight in kg captured per km
Div(no) = Shannon diversity based on numbers
Div(wt) = Shannon diversity based on weight

In some of the following material a modified Iwb is calculated, in which an Iwb value is derived with carp deleted from the numbers and biomass captured, but included in calculating the diversity values. This parameter has been of value in some state-wide studies (Ohio EPA).

Computer software for three dimensional graphs has made it possible to summarize substantial amounts of data over space and time. Most of the figures which follow were generated using BoeingGraph, version No. 4.0, 3D power graphics and Compaq Portable II or Zenith 386 computers with a Hewlett Packard LaserJet Series II printer. Some of the graphs were generated using Harvard Graphics, version 2.301 and AXUM. The graphs have been very useful in helping to interpret trends over time and space in addition to summarizing large amounts of information for this report.

Species of Fishes
in the middle Wabash River

The Wabash River possesses a diverse and abundant ichthyofauna. Table 8 summarizes all of the species which have been collected during the regular collecting series since 1967 and, in addition, includes species of smaller fishes which have been taken in special studies utilizing the seine. Scientific terminology follows Robins et al. (1991).

Only a few of these species were distributed uniformly throughout the 274 km (160 mile) study segment and only a very few species of fish subject to collection by electrofishing were truly abundant. A few other species populations were moderately abundant, but most species populations were relatively small and scattered.

An electrofishing run by Graduate students Brandon Kulik, Ernest Roggelin, and Rick Wright.

Table 8: List of fish species collected from the middle
Wabash River from 1967 to 1994.

_____FAMILY, Common Name, and _Scientific Name_____

Lamprey Family - PETROMYZONTIDAE

American brook lamprey - _Lampetra appendix_ (DeKay)
Silver lamprey - _Ichthyomyzon unicuspis_ Hubbs and Trautman
Chestnut lamprey - _Ichthyomyzon castaneus_ Girard

Sturgeon Family - ACIPENSERIDAE

Shovelnose sturgeon - _Scaphirhynchus platorynchus_ (Rafinesque)

Paddlefish Family - POLYODONTIDAE

Paddlefish - _Polyodon spathula_ (Walbaum)

Gar Family - LEPISOSTEIDAE

Longnose gar - _Lepisosteus osseus_ (Linnaeus)
Shortnose gar - _Lepisosteus platostomus_ Rafinesque
Spotted gar - _Lepisosteus oculatus_ (Winchell)

Bowfin Family - AMIIDAE

Bowfin - _Amia calva_ Linnaeus

Mooneye Family - HIODONTIDAE

Goldeye - _Hiodon alosoides_ (Rafinesque)
Mooneye - _Hiodon tergisus_ Lesueur

Freshwater Eel Family - ANGUILLIDAE

American eel - _Anguilla rostrata_ (Lesueur)

Herring Family - CLUPEIDAE

Skipjack Herring - _Alosa chrysochloris_ (Rafinesque)
Gizzard shad - _Dorosoma cepedianum_ (Lesueur)

Table 8: (continued)

Minnow Family - CYPRINIDAE

Stoneroller - *Campostoma anomalum* (Rafinesque)
Goldfish - *Carassius auratus* (Linnaeus)
Spotfin shiner - *Cyprinella spiloptera* (Cope)
˙Steelcolor shiner - *Cyprinella whipplei* Girard
Carp - *Cyprinus carpio* Linnaeus
Mississippi silvery minnow - *Hybognathus nuchalis* Agassiz
˙Redfin shiner - *Lythrurus umbratilis* (Girard)
*Speckled chub - *Macrhybopsis aestivalis* (Girard)
Silver chub - *Macrhybopsis storeriana* (Kirtland)
River chub - *Nocomis micropogon* (Cope)
˙Golden shiner - *Notemigonus crysoleucus* (Mitchill)
Bigeye chub - *Notropis amblops* (Rafinesque)
Emerald shiner - *Notropis atherinoides* Rafinesque
˙River shiner - *Notropis blennius* (Girard)
˙Ghost shiner - *Notropis buchanani* Meek
Silverjaw minnow - *Notropis buccata* Cope
Rosyface shiner - *Notropis rubellus* (Agassiz)
Striped shiner - *Notropis chrysocephalus* (Rafinesque)
Sand shiner - *Notropis stramineus* (Cope)
˙Mimic shiner - *Notropis volucellus* (Cope)
Suckermouth minnow - *Phenacobius mirabilis* (Girard)
Bluntnose minnow - *Pimephales notatus* (Rafinesque)
Bullhead minnow - *Pimephales vigilax* (Baird and Girard)
Creek chub - *Semotilus atromaculatus* (Mitchill)
˙Blacknose dace - *Rhinichthys attratulus* (Hermann)

Sucker Family - CATOSTOMIDAE

Northern river carpsucker - *Carpiodes carpio* (Rafinesque)
Quillback carpsucker - *Carpiodes cyprinus* (Lesueur)
Highfin carpsucker - *Carpiodes velifer* (Rafinesque)
White sucker - *Catostomus commersoni* (Lacepede)
Blue sucker - *Cycleptus elongatus* (Lesueur)
Northern hog sucker - *Hypentelium nigricans* (Lesueur)
Smallmouth buffalo - *Ictiobus bubalus* (Rafinesque)
Bigmouth buffalo - *Ictiobus cyprinellus* (Valenciennes)
Black buffalo - *Ictiobus niger* (Rafinesque)
Spotted sucker - *Minytrema melanops* (Rafinesque)
Black redhorse - *Moxostoma dequesnei* (Lesueur)

Table 8: (continued)

Sucker Family - CATOSTOMIDAE (continued)

Golden redhorse - *Moxostoma erythrurum* (Rafinesque)
Silver redhorse - *Moxostoma anisurum* (Rafinesque)
Shorthead redhorse - *Moxostoma macrolepidotum* (Lesueur)
River redhorse - *Moxostoma carinatum* (Cope)

Catfish Family - ICTALURIDAE

Black bullhead - *Ameiurus melas* (Rafinesque)
Yellow bullhead - *Ameiurus natalis* (Lesueur)
Blue catfish - *Ictalurus furcatus* (Lesueur)
Channel catfish - *Ictalurus punctatus* (Rafinesque)
Stonecat - *Noturus flavus* Rafinesque
*Mountain madtom - *Noturus eleutherus* Jordan
*Brindled madtom - *Noturus miurus* Jordan
*Freckled madtom - *Noturus nocturnus* Jordan & Gilbert
Flathead catfish - *Pylodictis olivaris* (Rafinesque)

Pike Family - ESOCIDAE

Grass pickerel - *Esox americanus* Gmelin

Codfish Family - GADIDAE

Burbot - *Lota Lota* (Linnaeus)

Killifish Family - CYPRINODONTIDAE

Blackstripe topminnow - *Fundulus notatus* (Rafinesque)

Silversides Family - ATHERINIDAE

*Brook silversides - *Labidesthes sicculus* (Cope)

Temperate Bass Family - PERCICHTHYIDAE

White bass - *Morone chrysops* (Rafinesque)
Yellow bass - *Morone mississippiensis* Jordan and Eigenmann
White bass x Striped bass hybrid

Table 8: (continued)

Sunfish Family - CENTRARCHIDAE

Rock bass - *Ambloplites rupestris* (Rafinesque)
Green sunfish - *Lepomis cyanellus* Rafinesque
Pumpkinseed - *Lepomis gibbosus* (Linnaeus)
*Orangespotted sunfish - *Lepomis humilis* (Girard)
Longear sunfish - *Lepomis megalotis* (Rafinesque)   -
Warmouth - *Lepomis gulosus* (Cuvier)
Bluegill - *Lepomis macrochirus* Rafinesque
Redear sunfish - *Lepomis microlophus* (Gunther)
Smallmouth bass - *Micropterus dolomieu* Lacepede
Spotted bass - *Micropterus punctulatus* (Rafinesque)
Largemouth bass - *Micropterus salmoides* (Lacepede)
White crappie - *Pomoxis annularis* Rafinesque
Black crappie - *Pomoxis nigromaculatus* (Lesueur)

Perch Family - PERCIDAE

Greenside darter - *Etheostoma blennioides* Rafinesque
Rainbow darter - *Etheostoma caeruleum* Storer
*Fantail darter - *Etheostoma flabellare* Rafinesque
Johnny darter - *Etheostoma nigrum* Rafinesque
*Orangethroat darter - *Etheostoma spectabile* (Agassiz)
Logperch - *Percina caprodes* (Rafinesque)
*Blackside darter - *Percina maculata* (Girard)
Slenderhead darter - *Percina phoxocephala* (Nelson)
*Dusky darter - *Percina sciera* (Swain)
*River darter - *Percina shumardi* (Girard)
Sauger - *Stizostedion canadense* (Smith)
Walleye - *Stizostedion vitreum* (Mitchill)

Drum Family - SCIAENIDAE

Freshwater drum - *Aplodinotus grunniens* Rafinesque

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* Species collected with a seine during special studies
(Rogellin 1979, EA Science and Technology 1988, 1989).
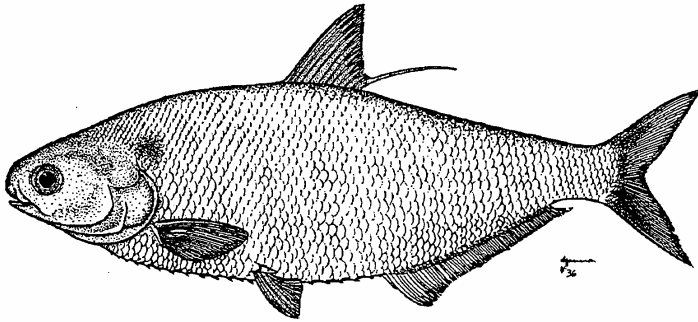
Gizzard Shad - *Dorosoma cepedianum*

Gizzard shad are the most abundant and important fishes in the Wabash River. Small shad less than 35 mm long feed almost exclusively on microcrustaceans (Warner 1940; Kutkuhn 1958; Dalquest and Peters 1966; Cramer and Marzold 1970). Larger individuals are well equipped morphologically to feed on and digest detritus (Mundahl and Wissing 1988), but also feed on zooplankton, phytoplankton, and other live foods when it is available and abundant (Jester and Jensen 1972; Jude 1973; Drenner et al. 1982, 1984). In tributaries of the Wabash River we have observed schools of shad feeding on tufts of aufwuchs/periphyton growing on submerged tree branches.

In the Wabash River, dense schools of shad frequent the quiet waters of backwater areas and shallow, sandy on the insides of river bends. They are much less common in faster water where most of the collecting sites were located.

Prior to 1981 gizzard shad constituted about half of the total numerical electrofishing catch and about 20% of the biomass. Shad abundance declined after 19081 for reasons to be discussed later and, since then has comprised about 30% of the total numbers and about 10% of the biomass.

In order to make valid comparisons of data from year to year, we have excluded young-of-the-year (y-o-y) fish of all species of fish from the catch and community analyses. This was necessary because favorable water levels for collecting fish sometimes occurred during June, before the appearance of y-o-y, but more often occurred during August when y-o-y were susceptible to capture by electrofishing. Population studies which ignore this practical reality run the risk of making invalid comparisons.

Gizzard shad spawn in early summer. Mancini (1974) found the highest density of shad fry in mid-June, with a secondary smaller peak in density in early July. Very

few ichthyoplankton eggs or fry were taken after July 20, 1973. Ichthyoplankton drift studies near the Wabash electric generating station indicated that gizzard shad fry constituted 40.1% and 84.1% of the total number of fry in 1973 and 1974, respectively (Gammon 1976).

Because of their abundance during early summer, small gizzard shad fry and y-o-y are probably an important food source for smaller piscivores, and perhaps for larger ones as well. In assessments of food habits of larger piscivores by Rud (1982), however, larger shad were found to be an unimportant food source.

Catch rates of gizzard shad one year old and older fluctuated considerably from year to year (Figure 41). Catch rates were

quite stable at 10-30/km from 1973 to 1979. Relative abundance declined to 5-20/km from 1980 through 1991. An enormously successful 1991 year-class produced the largest shad populations ever found one year later in 1992. As will be shown later, low shad densities for several years after 1984 were probably the result of a large aggregate population of piscivorous fishes. The piscivore population had diminished by 1991 and no longer cropped off young shad. This reduction in biological control, together with a favorable discharge pattern during summer, combined to generate a hugh 1991 year-class of shad.

This 1991 year-class was virtually exterminated by the prolonged high water in 1993, as was the entire 1993 year-class of shad and most other species.

The temporal pattern of average weight is a mirror image of the catch rate. During years with low catch rates the shad were generally larger, older fish while high catch rates included more successful, younger year classes. The shift in size is best shown by examining the changes in length frequency over time. Figure 42 shows the large number of yearling shad in 1974, 1979, and 1992, the result of unusual spawning success each of the previous years. Figure 42 also indicates the preponderance in the catches of larger shad from 1986 through 1990.

Reaches 4 and 5 supported more shad than other Reaches (Figure 43) and Reach 8 consistently yielded fewer shad and larger individuals than most other Reaches. The cause(s) for this scarcity of an otherwise ubiquitous species is unknown.

Figure 41: Annual catch rates and mean weight of gizzard shad from 1968 through 1994.
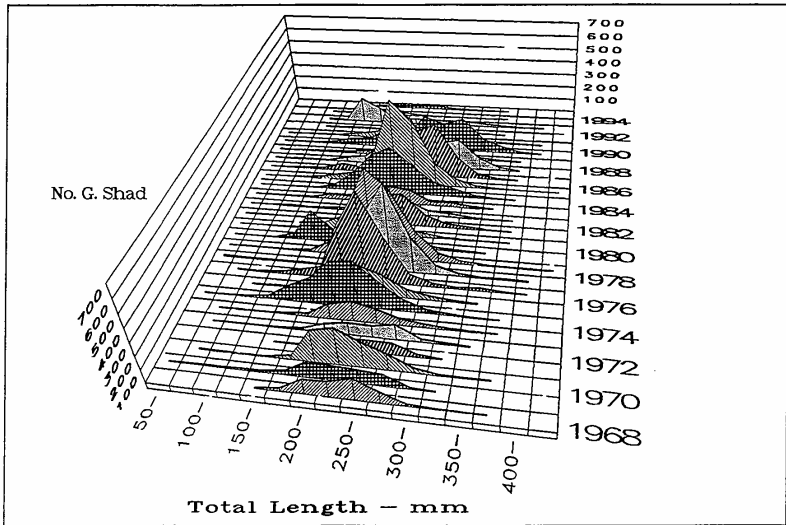
Figure 42: Length frequency of gizzard shad from 1968 through 1994.
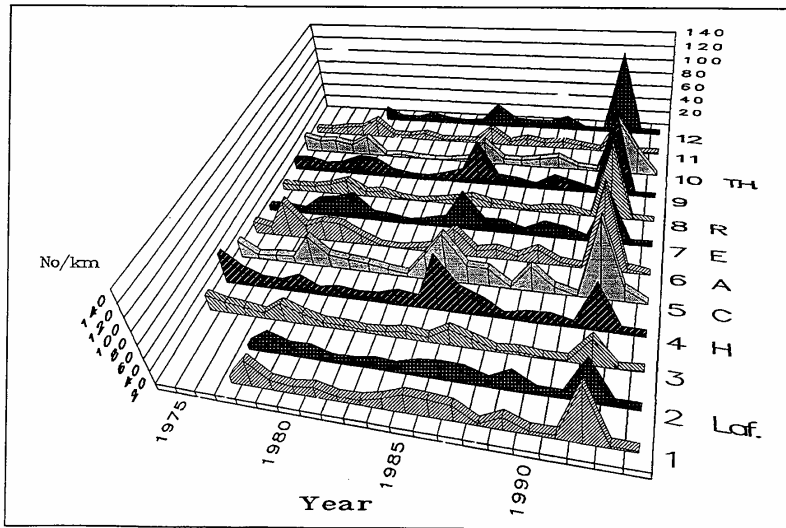
Figure 43: Catch rates (No/km) of gizzard shad from 1974 through 1994.
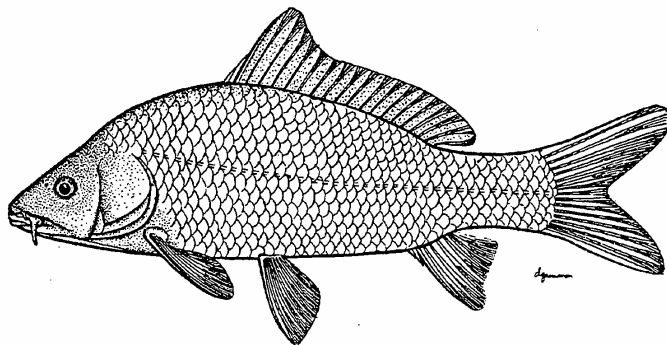
Carp - *Cyprinus carpio*

Carp is another species distributed commonly throughout the middle Wabash River. Although they made up only 10% to 15% of the electrofishing catch numerically, they contributed 30% to 50% of the biomass.

From the time trends summarized in Figure 44 it appears as if carp have steadily decreased in abundance and increased in mean size over the period of study. That would be an erroneous conclusion, however.

The relatively high catch rates indicated for the period 1974 through 1978 and also the correspondingly small mean size for much of that period were both the result of an unusual mainstem spawning event in 1973. An ichthyoplankton drift study was underway at that time. On June 11, 1973 a first indication of something unusual was evidenced by the sudden appearance of tiny carp fry averaging 7.5 mm in total length. These fry continued to be captured in drift nets until June 29, growing at a rate of 1.18 mm each day (Gammon 1976). Their

appearance as ichthyoplankton coincided exactly with a period of late flooding from June 5 to June 10, 1973 during which time flood waters submerged the riparian vegetation which bordered the river, creating ideal conditions for spawning.
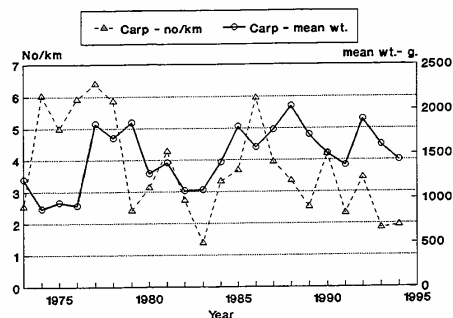
Figure 44: Annual mean catch rate (No/km) and mean weight of carp from 1968 through 1994.

It appears that this spawning event was primarily responsible for the abundance of small carp in the Wabash River from 1974 through 1978. Since 1978 both the catch rate and mean size appear to have fluctuated around horizontal plateaus without indications of either increase or decrease. However, Glander (1984, 1987) has also noted a general decrease in the size of the commercial catch of carp from 1977 through 1986.

An abundance of carp is often regarded as an indicator of degraded environmental conditions which could support few other less hardy species. In the middle Wabash River, however, the largest catch rates generally were found in the stretch of river from Delphi, Indiana through Covington, Indiana (Reaches 1 - 5) as well as in the lower reaches downriver from Terre Haute, Indiana (Reach 10) (Figure 45). Catch rates were lower from the Cayuga electric generating station to Terre Haute, Indiana (Reaches 6 - 9).
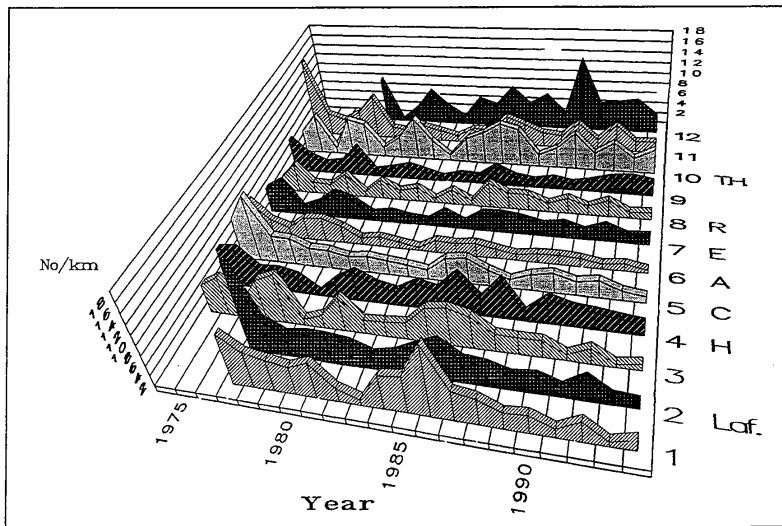
Figure 45: Catch rates (No/km) of carp in 12 Reaches of the Wabash River from 1974 through 1994.
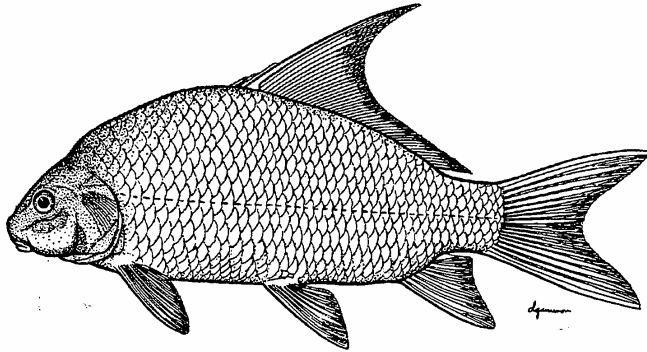
Northern River carpsucker - *Carpiodes carpio*
Quillback carpsucker - *Carpiodes cyprinus*
Highfin carpsucker - *Carpiodes velifer*

All three species of carpsuckers are similar in general appearance and habits. They travel in sizeable schools feeding on the bottom detritus and small invertebrates. The quillback or sickleback is shown above.

By far the most common carpsucker in the Wabash River collected by electrofishing is the northern river carpsucker *Carpiodes carpio*. It is a big river species which rarely enters tributaries. As with many other species in the Wabash River, it increased in abundance after 1984 (Figure 46). It is also highly susceptible to capture by electrofishing and peak catches were made during 1977 and 1988. The average size appears to have decreased very gradually since about 1977.

Although this species was taken throughout the middle Wabash River it was consistently more abundant in the upper six Reaches of the study segment and especially from Delphi, Indiana through Lafayette,

Indiana (Figure 47). Catches downriver from Reach 6, the Cayuga EGS, were low and sporadic prior to 1984, after which time they increased consistently.
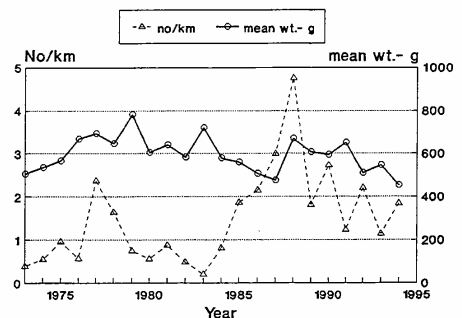
Figure 46: **Annual mean catch rate (No/km) and mean weight of northern river carpsucker from 1968 through 1994.**
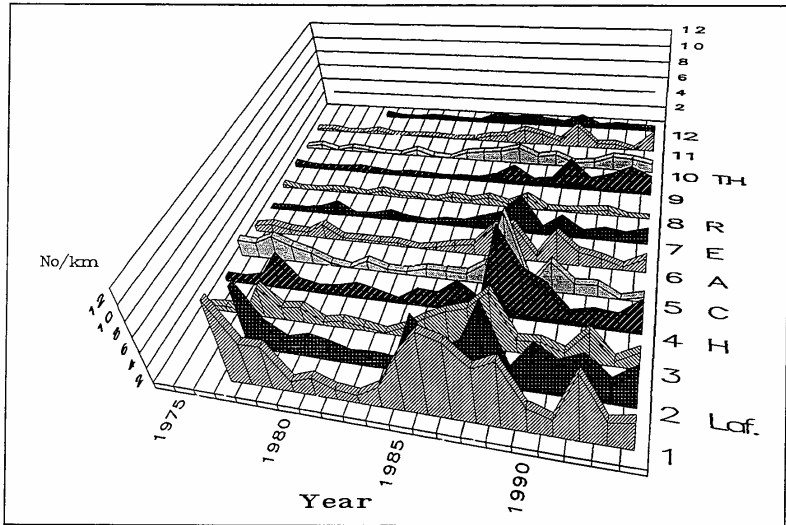
**Figure 47: Catch rates (No/km) of northern river carpsucker
in 12 Reaches of the Wabash River from 1974 through 1994.**

During the August 1988 drought, well after the electrofishing catches had been completed, we observed many large dead carpsuckers floating downriver in the Coal Creek area. River discharge was very low at the time and ambient temperatures exceeded 32° C (90° F). Electrofishing collections taken earlier that summer, also during very low water conditions, were about normal in comparison to other recent years.

Two other species of carpsuckers were taken less frequently, but in approximately equal numbers, the quillback *Carpiodes cyprinus* and the highfin carpsucker *Carpiodes velifer*. Both of these species probably enter the Wabash River from smaller, cooler tributaries which harbor permanent populations. Few individuals of quillback were found downriver from Montezuma, Indiana until about 1984, after which small numbers appeared nearly everywhere (Figure 48).
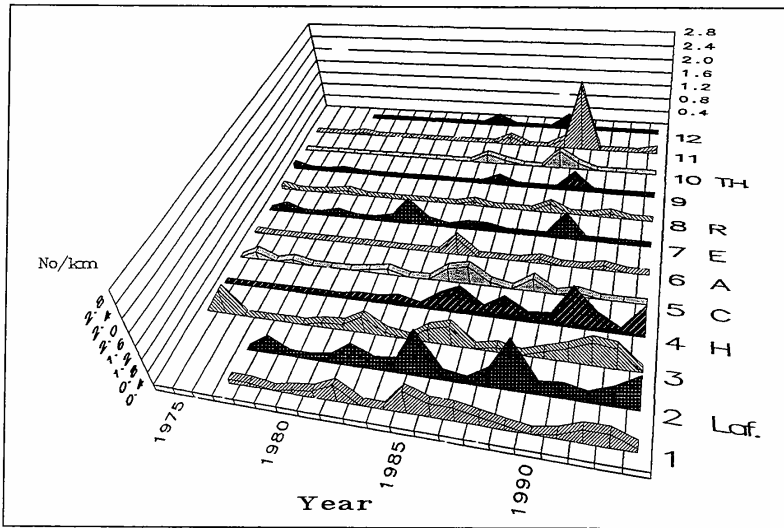
Figure 48: Catch rates (No/km) of quillback carpsucker in 12 Reaches of the Wabash River from 1974 through 1994.

Sue Gilbertson weighs a carp.

Silver Redhorse - *Moxostoma anisurum*
River Redhorse - *Moxostoma carinatum*
Black Redhorse - *Moxostoma duquesnei*
Golden Redhorse - *Moxostoma erythrurum*
Shorthead Redhorse - *Moxostoma macrolepidotum*

Five species of redhorse are regularly taken by electrofishing in the middle Wabash River. In order of numeric abundance, they are (1) golden redhorse *Moxostoma erythrurum*, (2) shorthead redhorse *M. macrolepidotum*, (3) silver redhorse *M. anisurum*, (4) black redhorse *M. duquesnei*, and (5) river redhorse *M. carinatum*.

One additional redhorse species, the greater redhorse *Moxostoma valenciennesi* Jordan, is probably also present in small numbers. This species has been collected from two Wabash River tributaries, Otter Creek by Whitaker (1976) and the Eel River by Gammon and Gammon (1990). It could well have occurred in our catches, but may have been misidentified as river redhorse, a species it closely resembles.

All *Moxostoma* species are similar in size and basic appearance. Their bodies are streamlined and either round in cross-section or slightly flattened laterally. In color they are green-gold dorsally, bronze-colored laterally with white bellies. Silver, golden, and black redhorse have grayish tail fins, while all others have a bright red caudal fins. All have ventrally located mouths with large lower lips.

The river redhorse is the largest species on the average, while the slender black redhorse is the smallest. Most redhorse range from 300 to 600 mm (1 to 2 feet) in total length and weigh 0.5 to 1.5 kg (1 to 3 pounds), but some live long enough to become much larger.

All redhorse feed upon invertebrates living on and in the bottom substrate. Their large fleshy lips are abundantly provided with taste buds enabling them to taste and then eat succulent food items as they cruise over the bottom.

All redhorse are among the most thermally sensitive species of fish in the Wabash River (Gammon 1973, 1976). They are also intolerant of a wide variety of environmental disturbances including poor water quality and habitat degradation (Ohio Environmental Protection Agency 1987, Simon 1992).

By far the largest concentration of redhorse is in the upper part of the study section, especially upriver from Lafayette, Indiana where their numeric abundance approaches that of gizzard shad. Their abundance overall increased to the flood of 1993 when
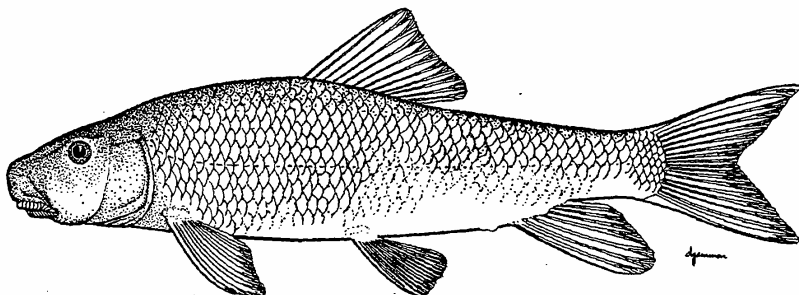
Golden Redhorse - *Moxostoma erythrurum*

Golden redhorse are widely distributed in medium and large streams in Indiana. They occur in sizeable schools in the pools of streams where they feed upon small invertebrates living on and in the bottom substrate. During spring they undertake spawning migrations into tributaries and are often sought by anglers at this time.

The electrofishing catches and the mean weight of golden redhorse increased from 1973 through 1986 and declined thereafter (Figure 49). The 1993 flood decimated the golden redhorse population.

Of the five *Moxostoma* species which live in the Wabash River, the golden redhorse is among the most abundant and common together with the shorthead redhorse. They are much more abundant upriver from Covington, Indiana than elsewhere (Figure 50). They are thermally sensitive species which were formerly common in Reach 6 before the Cayuga Electric Generating Station began operating.

Golden redhorse seem to have participated in the population expansion of the middle 1980's and even expanded into Reach 11 downriver from Terre Haute, Indiana.

It is likely, however, that golden redhorse normally reside in clean tributaries and move into only those sections of the Wabash River with better water quality and suitably cooler temperatures.
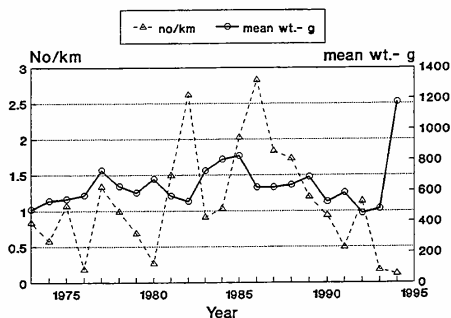
Figure 49: Annual catch rates and mean weight of golden redhorse from 1968 through 1994.
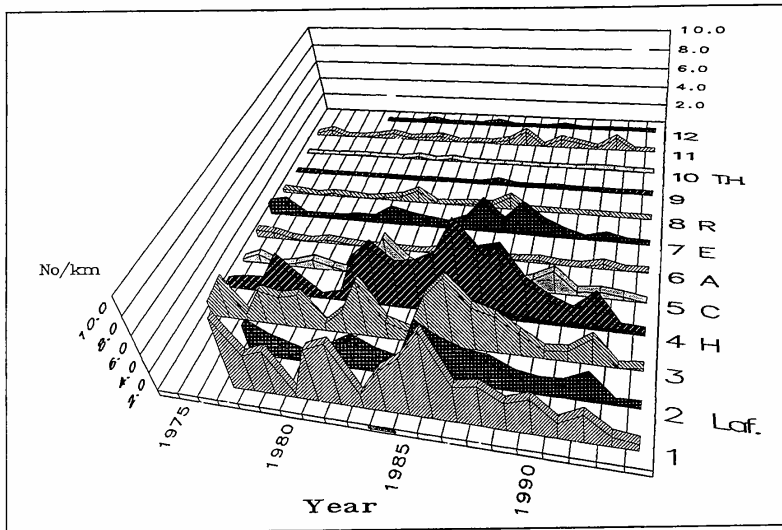
Figure 50: Catch rates (No/km) of golden redhorse
in 12 Reaches of the Wabash River from 1974 through 1993.

Chris Yoder records while Jim Thayer measures fish with Gary Milburne observing.
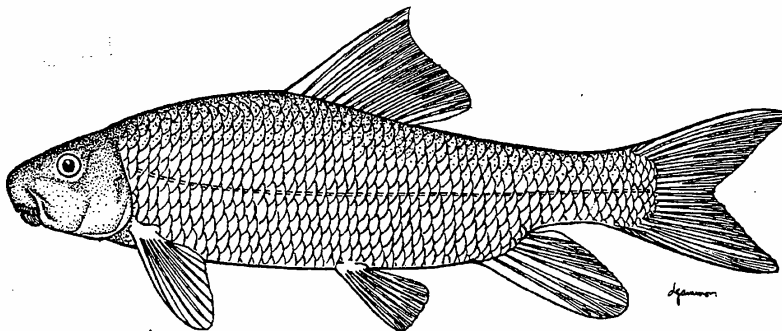
Shorthead Redhorse - *Moxostoma macrolepidotum*

Shorthead redhorse population abundance is about the same as golden redhorse in the Wabash River. However, it prefers to live and feed in faster-moving microhabitats of the river rather than in pooled sections. This "redtail" is prized by spring anglers for both its sporting attributes and its edibility.

The catch rate of shorthead redhorse approximately doubled from 1984 to 1992 (Figure 51). Remarkably, the average size increased during this same period, except for 1990 and 1991. The sharp decline in catch rate in 1993 and 1994 reflects the negative impact of the 1993 flood and not, as was previously postulated, an artifact of poor collecting conditions. There is, however, an indication that a population consisting of smaller individuals has been present since about 1990.

The shorthead redhorse is fairly common north of Montezuma, Indiana except in the vicinity of the Cayuga EGS (Figure

52). Some expansion of population density appears to have occurred since 1980 in Reaches 3, 4, and 5, between Lafayette and Cayuga, Indiana. They even appeared in small numbers at the Cayuga EGS during the high flow summers of 1989 and 1990. As is the case with golden redhorse, this species is also very scarce downriver from Clinton, Indiana.
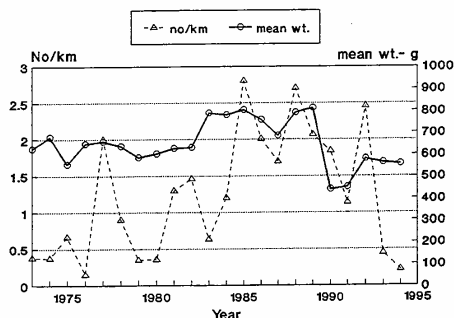
Figure 51: Mean annual catch rate and mean weight of shorthead redhorse from 1968 through 1994.
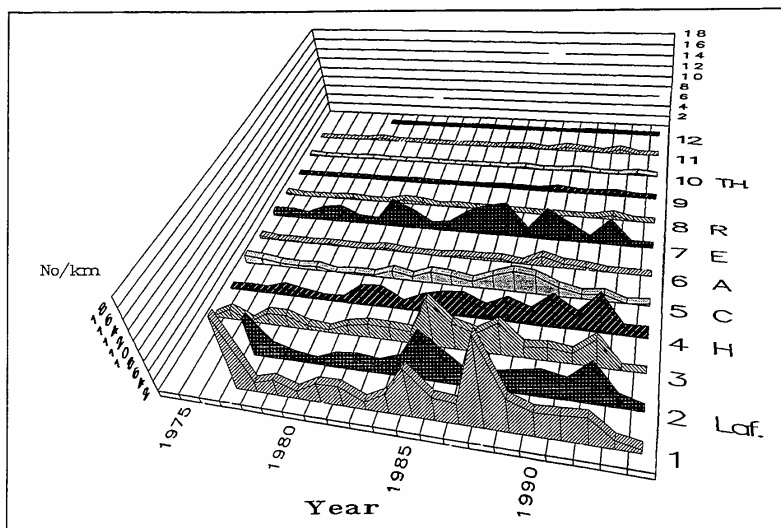
Figure 52: Catch rates (No/km) of shorthead redhorse
in 12 Reaches of the Wabash River from 1974 through 1994.
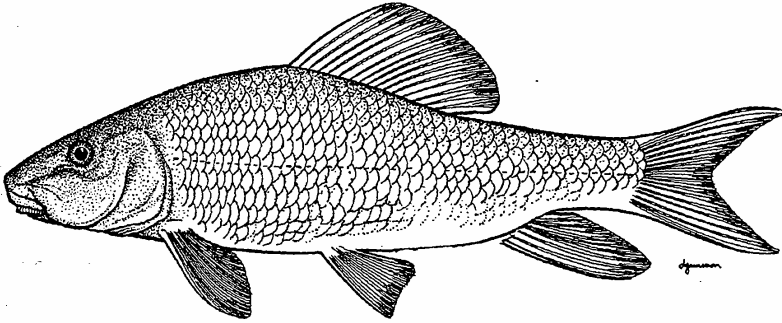
Silver Redhorse - *Moxostoma anisurum*

The silver redhorse population appears to be less than half as abundant as either golden redhorse or shorthead redhorse. However, both the population abundance and mean size have increased over the period of study (Figure 53). Silver redhorse seem to prefer deeper habitats and slower water than other redhorse species.

They are most common in Reach 1 upriver from Lafayette (Figure 54), but they were consistently found in good numbers in Reaches 2 through 7. Silver redhorse were relatively scarce in Reaches 4 through 7 until 1979-1980, when their numbers increased considerably. They began to appear in small numbers even in downriver Reaches 8 through 12 after that date.

Increasing numbers were captured at the Cayuga EGS (Reach 6) after 1985. The increase in numbers at this site was particularly large in 1988 when river flow was very low and temperatures often high. The increase here may be related to the altered operation of the Cayuga EGS, a subject which will be examined later.

Catches were about half as great after the 1993 flood than before, but the flood's negative effects were less on this species than for golden and shorthead redhorse.
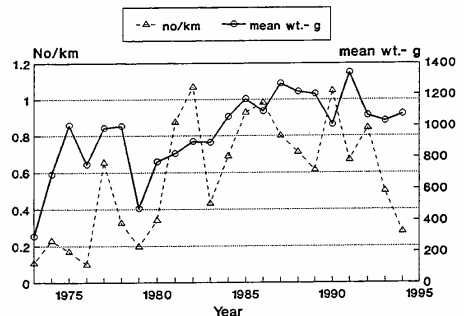
Figure 53: **Mean annual catch rate and mean weight of silver redhorse from 1968 through 1994**
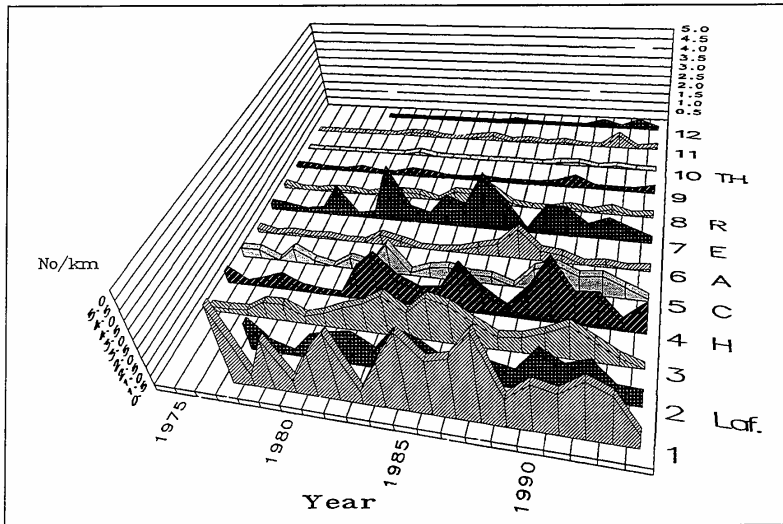
**Figure 54: Catch rates (No\km) of silver redhorse
in 12 Reaches of the Wabash River from 1974 through 1994.**
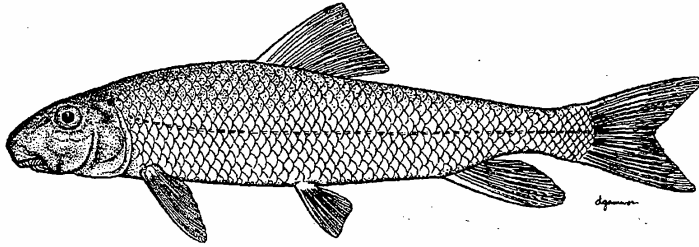
Black Redhorse - *Moxostoma duquesnei*

The black redhorse is restricted almost exclusively to the upper four Reaches from Delphi to Covington, Indiana. Rarely they have been found further downriver (Figure 55).

This smaller species generally inhabits smaller streams than golden, shorthead, and silver redhorse and no doubt enter the Wabash River mainstem from these tributaries.
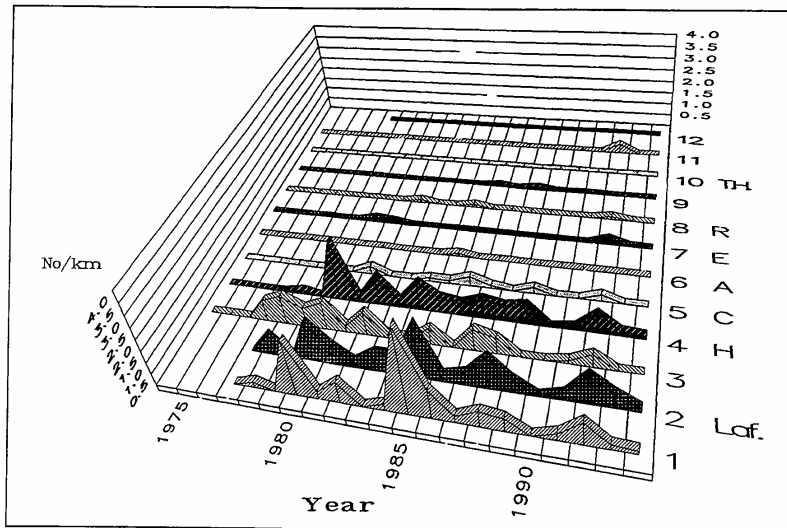
Figure 55: Catch rates (No\km) of black redhorse in 12 Reaches of the Wabash River from 1974 through 1994.
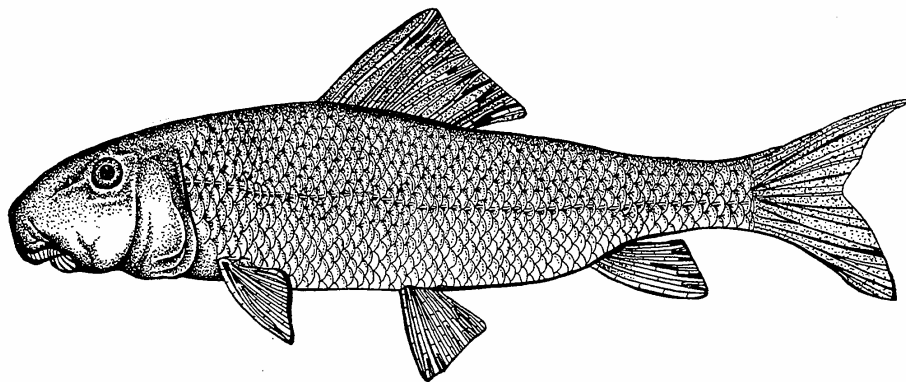
River Redhorse - *Moxostoma carinatum*

The river redhorse was originally described from specimens collected by Cope (1870) from the Wabash River at Lafayette, a section of river which still harbors a healthy population. This species superficially resembles a large golden redhorse, but has a red caudal fin. It appears to prefer swift, deep riffles where it feeds heavily on mollusks such as snails and small clams. As with other redhorse species, the pharyngeal arch is adapted to the food preferences of the species. For river redhorse the heavy pharyngeal arch possesses molarized teeth for grinding mollusks.

Although never common, the abundance of river redhorse increased somewhat from 1980 to 1989 (Figure 56). The average size also increased. Prior to 1982 river redhorse averaged 800 - 1200 g. After 1983 the average river redhorse captured weighed 1500 to 2000 grams. The 1993 flood has decimated the population and none have been taken since that event.

River redhorse were rarely seen downriver from Lafayette, Indiana until about 1980, after which time increasing numbers appeared in the catches between Lafayette, Indiana and Covington, Indiana (Reaches 2, 3, and 4) (Figure 55).
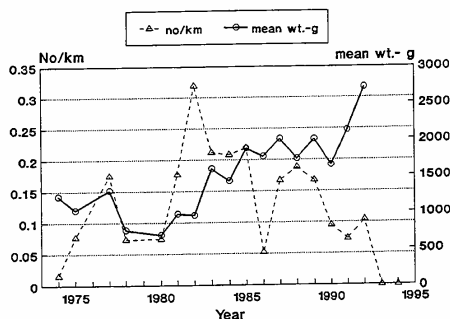
Figure 56: **Mean annual catch rate (No\km) and mean weight of river redhorse from 1968 through 1994.**
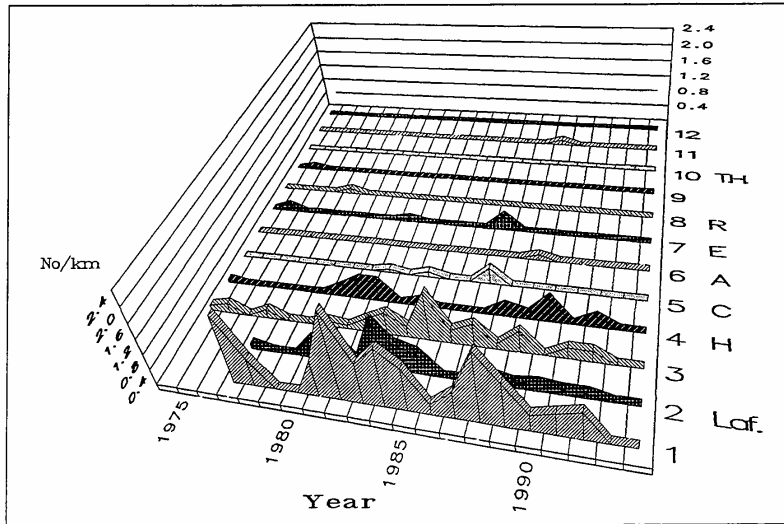
Figure 57: Catch rates (No\km) of river redhorse
in 12 Reaches of the Wabash River from 1974 through 1994.
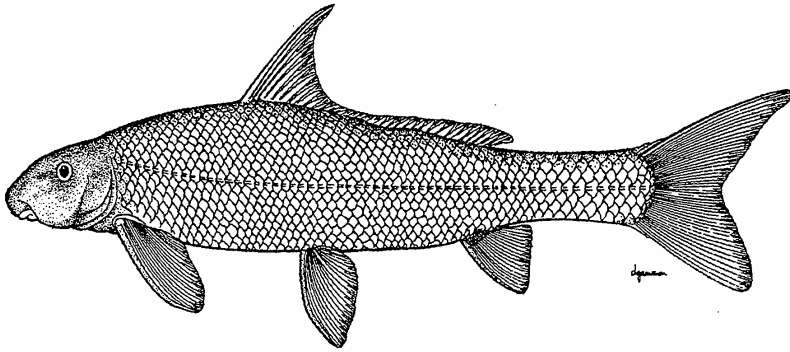
Blue Sucker - *Cycleptus elongatus*

The blue sucker is widely distributed in larger rivers from the Ohio and Missouri Rivers southward to the Rio Grande River. It inhabits deep, swift main channels of large streams and big rivers. Although it is locally abundant, Williams et al. (1989) indicate that it is declining throughout its range mainly because of habitat alteration. They recommended placing blue sucker on the species list of Special Concern, as did Whitaker and Gammon (1988) with regard to its status in Indiana.

Lesueur first described blue sucker in 1817 from specimens taken near Pittsburgh, Pennsylvania. It was common in the Ohio River before 1850, but declined dramatically from 1900 to 1950 (Pearson and Krumholz 1984). The Wabash River supports one of the few remaining sizeable populations.

There is little doubt that blue suckers spawn and live their entire lives in the Wabash River mainstem. Beyond that attribute, little has been learned about its spawning preferences or early life history because no small, young individuals have ever been found. Concentrations of adults and, perhaps, subadults occur in deep, swift chutes and they are especially abundant near the mouths of several larger tributaries, especially Sugar Creek and Coal Creek.
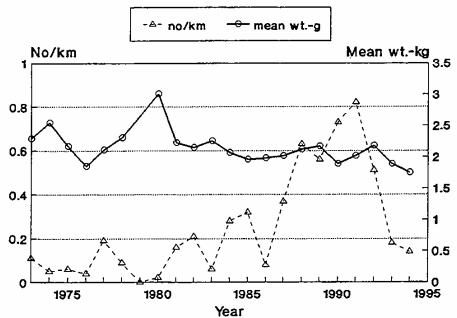
Figure 58: Mean annual catch rate and mean weight of blue suckers from 1968 through 1994.
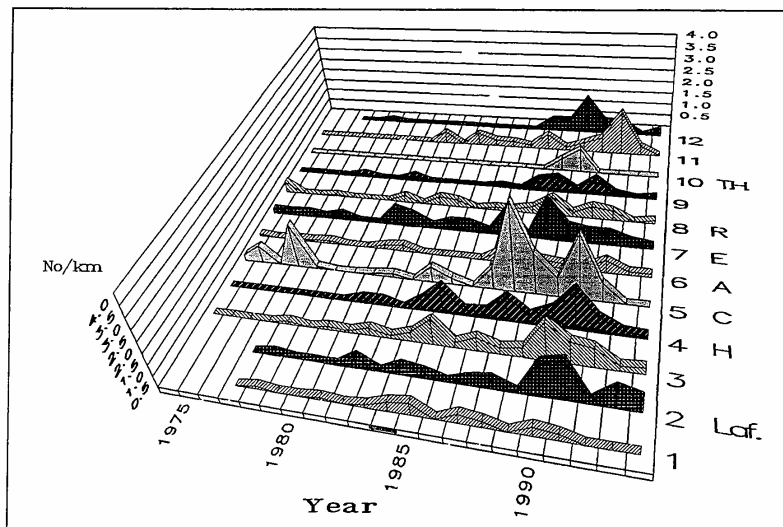
**Figure 59: Catch rates (No\km) of blue sucker in 12 Reaches
of the Wabash River from 1974 through 1994.**

Prior to 1984 electrofishing catch rates were less than 0.2/km (Figure 58). From 1985 to 1991 catch rates quadrupled. Catch rates fell to less than 0.2/km after the 1993 flood, but a population decline appeared to be in progress prior to that event.
The average size has also declined gradually over time with 1994 marking the lowest observed mean weight ever (N = 13).

Before 1978 most blue suckers were captured within a 65 km (40 mile) section of river between Cayuga and Terre Haute, Indiana (Figure 59). Very few individuals were found prior to that time either downriver from Terre Haute, Indiana or upriver from Covington, Indiana. Since then blue suckers have extended their range throughout the middle Wabash River and have also grown in density, particularly since 1984.

With the increase in range and numbers has come a greater diversification of sizes (Figure 60). Although no very small individuals have been found, there was a gradually increasing range of lengths collected from about 500-650 mm from the period 1968-1978 to about 425-750 by 1988. Since 1991 that trend has been reversed with both lower catch rates and reduced size ranges.

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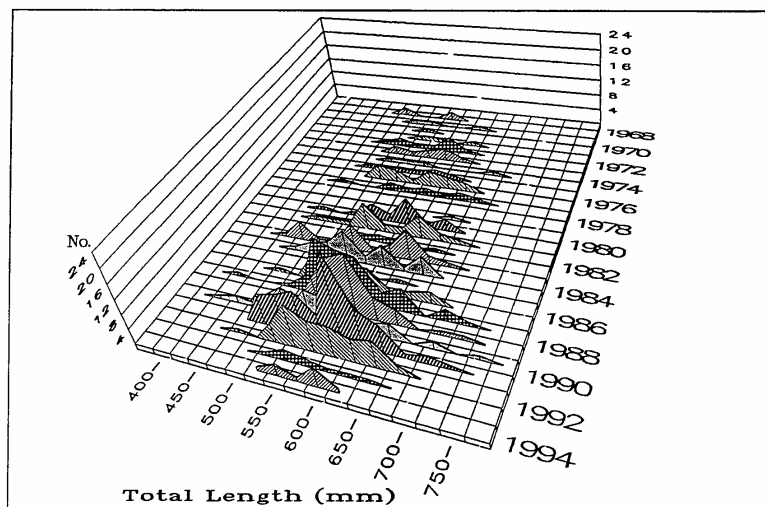
Figure 60: Length frequency of blue suckers 1968 - 1994.

A typical Wabash River blue sucker.

Smallmouth Buffalo - *Ictiobus bubalus*
Bigmouth Buffalo - *Ictiobus cyprinellus*
Black Buffalo - *Ictiobus niger*

Bigmouth Buffalo

Smallmouth Buffalo
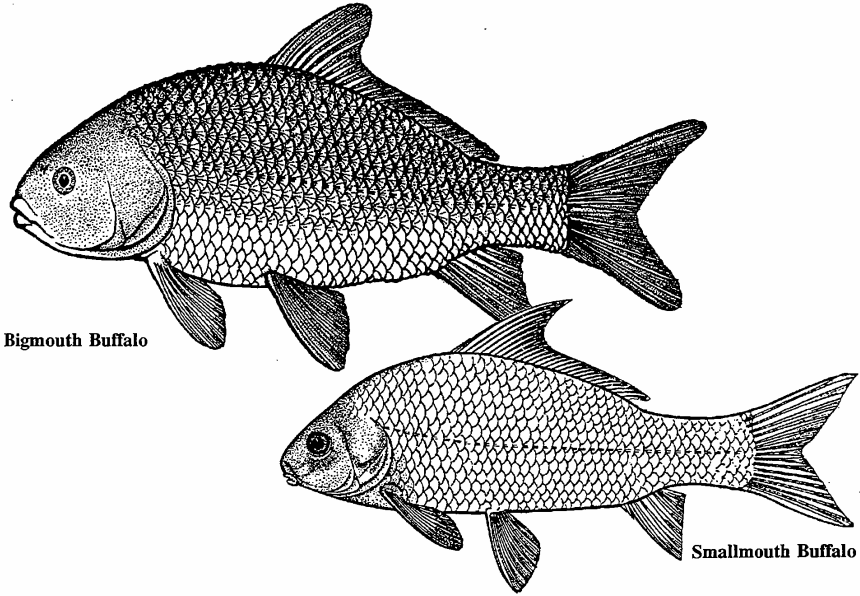
The buffalo or buffalofish are among the largest species of fish native to the Wabash River. Bigmouth buffalofish (*Ictiobus cyprinellus*) achieves a size of 25 kg (50 to 60 pounds); smallmouth buffalo (*Ictiobus bubalus*) is usually much smaller, but still may grow to 20 kg (40 to 45 pounds). The larger specimens are less easily collected by electrofishing than most other species simply because their large size and great strength often propel them through the electric field and beyond before they can be netted. Approximately twice as many smallmouth buffalofish have been taken by electrofishing than bigmouth buffalo over the period of study.

Buffalo are fairly good food fish, especially smallmouth buffalo. The larger individuals may be stuffed and baked. Large bigmouth buffalo are often smoked. Neither species is sought by anglers, but they do enter into the commercial catch and are regularly marketed in Indiana at the seafood section of grocers.

Despite belonging taxonomically to the same genus, smallmouth and bigmouth buffalo are adapted for quite different life-styles. Smallmouth buffalo (*Ictiobus bubalus*) superficially resemble large, muscular, dark-colored carpsuckers. They were most often

found in deep, fast-water chutes in company with river redhorse, blue sucker, and shovelnose sturgeon. They are opportunistic bottom feeders and eat a variety of foods including zooplankton, algae, insect larvae, and detritus (McComish 1967).

The average Wabash River small-mouth buffalo weighed 2 - 3 kg (4 - 7 pounds) (Figure 61). The catch rate of this species increased substantially after 1983, but the size remained fairly constant until recently. Smallmouth buffalo were most common upriver from Montezuma in Reaches 1 through 6 (Figure 62), and especially in Reach 3 from Lafayette to Covington, Indiana.
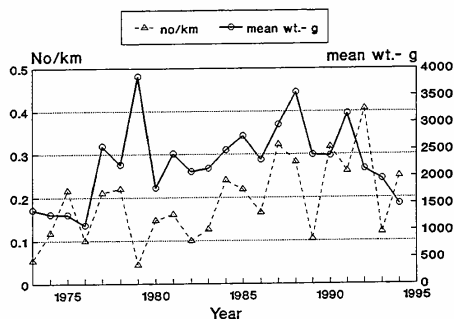
Figure 61: Mean annual catch (No/km) and mean weight of smallmouth buffalo from 1968 through 1994.
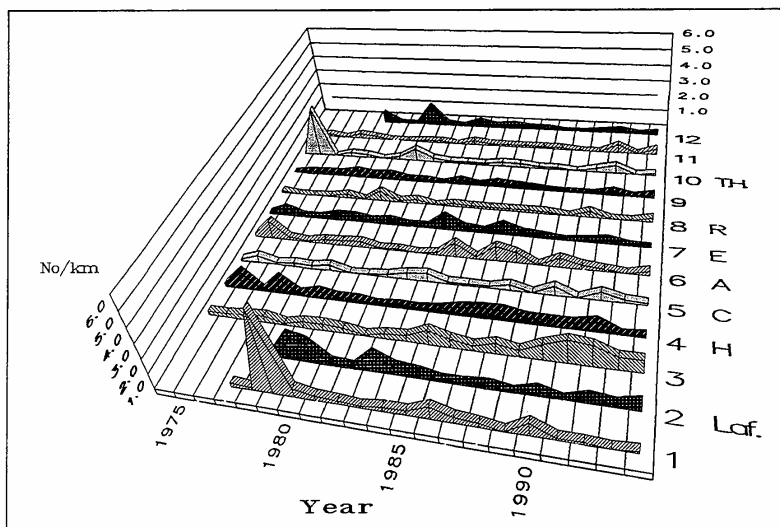
Figure 62: Catch rates (No\km) of smallmouth buffalo in 12 Reaches of the Wabash River from 1974 through 1994.

The bigmouth buffalo (*Ictiobus cyprinellus)* feeds primarily by filtering microcrustaceans from the water column. The mouth is in the usual terminal location and not subterminal as with all other members of the Catostomidae. The gills are fitted with long, comb-like gill rakers for feeding on small planktonic and bottom invertebrates.

Bigmouth buffalo were most often encountered in the Wabash River near ashpond effluents and backwater areas in which zooplankton populations flourish. Elsewhere in Indiana, they are especially common and large in waters below the larger dams and reservoirs where they fatten on zooplankton suspended in release water. The catch rate of bigmouth buffalo in the Wabash River was low and evenly distributed nearly everywhere (Figure 63). Catches of this species have been extremely low throughout the middle Wabash River since about 1988.

A third species of buffalo, the black buffalo (*Ictiobus niger)* was much less common than either of the other species with only 22 specimens having been positively identified since studies began in 1967. It most resembles the smallmouth buffalo, but is darker in coloration and more slender. Trautman (1981) states that it prefers habitat intermediate to the other two species.
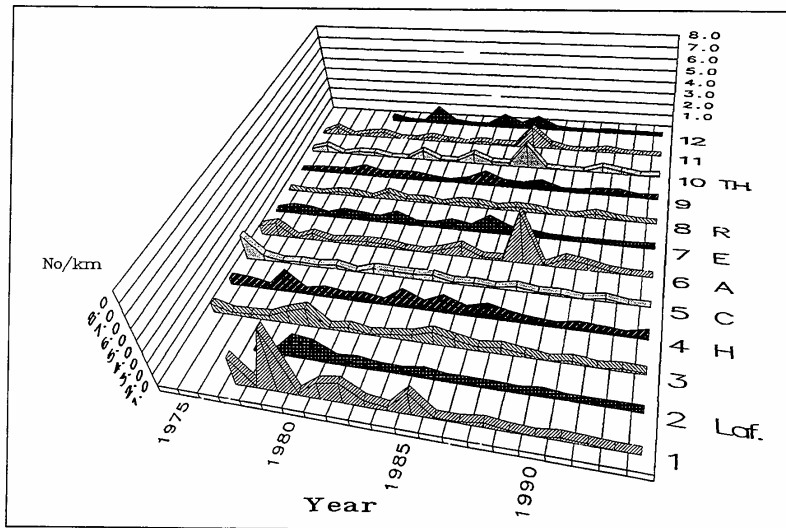
Figure 63: Catch rates (No\km) of bigmouth buffalo
in 12 Reaches of the Wabash River from 1974 through 1994.

Other Small Catostomids

Several smaller members of the Family Catostomidae were present in small numbers in the Wabash River. A very few spotted sucker (*Minytrema melanops)* and white sucker (*Catostomus commersoni)* were collected, although both of these species are more common in tributaries.

One very distinctive sucker which occurs in modest numbers in the Wabash River and flourishes in tributary riffles is the northern hog sucker (*Hypentelium nigricans*). Hog suckers are not exactly beautiful, but they are extremely well adapted for life in flowing water. The broad head, which tapers to a small caudal fin, is fitted ventrally with a mouth like a vacuum-cleaner and dorsally with a broad indentation between the eyes for channeling flowing water up and over the head and body. Furthermore, hog suckers possess hugh pectoral fins behind the head

that spread out like wings. The mottled, brown body blends in surprising well with riffle rocks. Ungainly they may appear to be, but they are so well designed that little energy needs to be expended for living in fast water. The fast current sweeping over the head and pectoral fins literally glues the fish to the bottom.

Hog suckers are obviously suited to feeding on bottom invertebrates and may be observed moving about sucking fine materials and small animals from among rocks. They have been known to take small spinners and may also occasionally feed on small fish.

Hog suckers are mostly restricted to the upper Reaches of the Wabash River study segment (Figure 64). Neither the density nor the distribution has changed over the period of study.
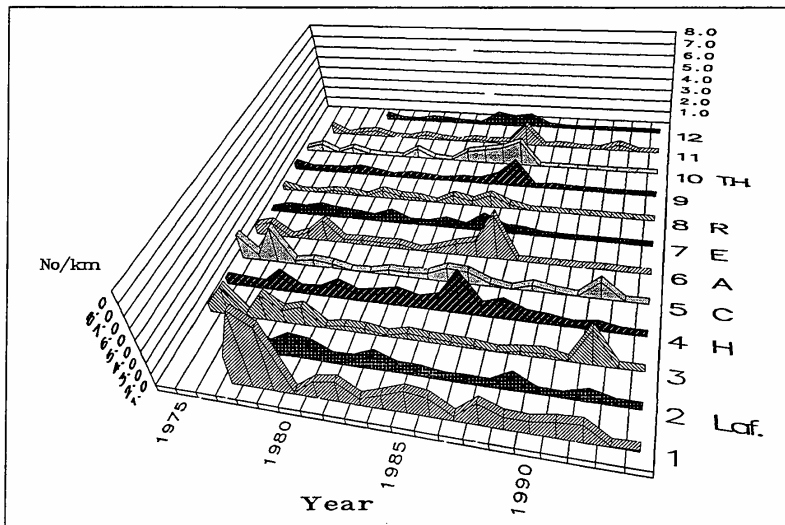
Figure 64: Catch rates (No\km) of hog sucker in 12 Reaches of the Wabash River from 1974 through 1994.

Part of the 1977 fish collecting crew after three days on the river at Beezer's cabin.
At left and top-center are two unidentified Purdue University students.
Others from left to right are Bob Gammon, Mike Stroup, Brandon Kulik, Dave Petree,
Dr. Jerry Hamelink, and Jim Thayer.
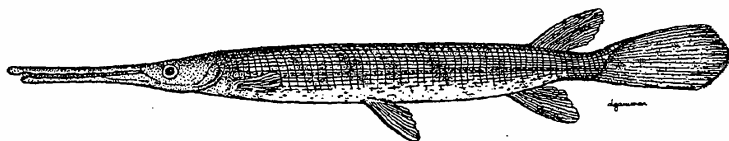
Longnose Gar - *Lepisosteus osseus*
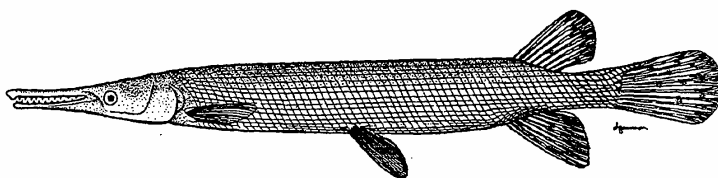
Shortnose Gar - *Lepisosteus platostomus*
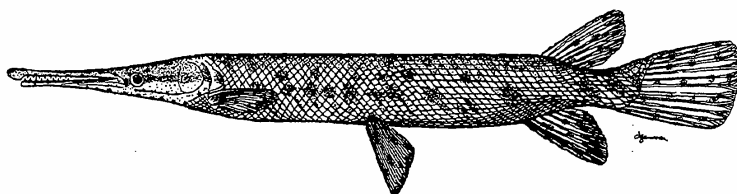
Spotted Gar - *Lepisosteus oculatus*

Longnose gar - *Lepisosteus osseus*
Shortnose gar - *Lepisosteus platostomus*
Spotted gar - *Lepisosteus oculatus*

Fossil gar specimens have been found in North America, Europe, Africa, and India, but the seven living species are now restricted to the Western Hemisphere from Costa Rica to southern Canada (Wiley 1976).

The Wabash River contains four species of these ancient fishes, but we have taken only three species in the middle Wabash River; longnose gar (*Lepisosteus osseus*), shortnose gar (*Lepisosteus platostomus*), and spotted gar (*Lepisosteus oculatus*). Alligator gar (*Lepisosteus spatula*) was recorded in the lower Wabash River at New Harmony by Jordan (1890). It had not been taken again until 1993 when specimens were found in the lower White River (Lydy, personal communication) and in the lower Wabash River (T. Simon, personal communication). Alligator gar has declined in abundance in the Ohio River according to Pearson and Krumholz (1984), although it was never common.

Gar inhabit larger rivers, lakes, and swamps within their range and even frequent brackish coastal waters. Their air bladder functions as a "lung", enabling them to take in air at the water surface and exist in waters with low dissolved oxygen such as swamps and weedy backwater bayous. Gar are carnivores which feed primarily on living and dead fish. Because of their supposed competition with more desirable piscivorous species gar are often regarded with contempt by anglers, especially since they are inedible. The greenish-colored eggs of the female are toxic, but the flesh of adults is sometimes smoked and eaten.

The spotted gar is uncommon in the middle Wabash River and only a few specimens are collected each year. Those which are taken may have strayed from their normal habitat in the northern lakes or from the oxbow lakes and weedy ditches of the lower Wabash River basin.

Longnose gar and shortnose gar are both common and widely distributed. They have been collected in approximately equal numbers over the years. The numbers of both species captured by electrofishing fluctuated considerably from year to year (Figures 65 and 66). Fluctuations in catch rates are similar for both species with lower catch rates generally coinciding with summers having lower rates of discharge. The density of shortnose gar seems to have increased slightly over the period of study. The average size of longnose gar appears to have increased somewhat since 1984.
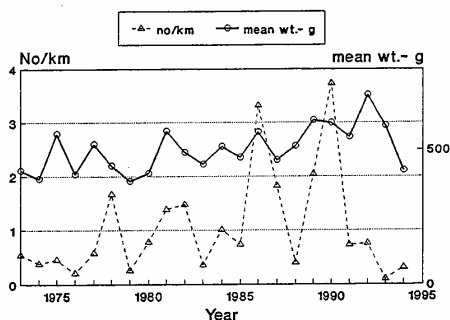
Figure 65: Mean annual catch (No\km) and mean weight of longnose gar from 1968 through 1994.

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Longnose gar are equally common nearly everywhere (Figure 67). However, shortnose gar are scarce north of Lafayette and are particularly abundant from Terre Haute south (Figure 68).

These distributional patterns of the adults and subadults may be related to differences in spawning preferences and available spawning habitat. Longnose gar ascend tributaries to spawn in the spring. Sugar Creek, for example, sometimes has a large migration with some fish entering even some of its smaller tributaries. By late summer small young-of-the-year longnose gar may be seen in the sandy shallows of the inside bends of the river.

Shortnose gar, on the other hand, spawn in the sluggish, weedy tributaries and oxbows which make their appearance south of Terre Haute, Indiana. Large numbers of smaller shortnose gar can often be observed near the surface of weedy tributary ditches during the summer.

Since 1984 both species of gar have become more common than formerly in the lower part of the study section. Increased numbers of both longnose and shortnose gar are now found at and downriver from the Cayuga Electric Generating Station (Reaches 6 through 12). However, there has been little change in the densities of either species in the upper Reaches (Reaches 1 through 5).
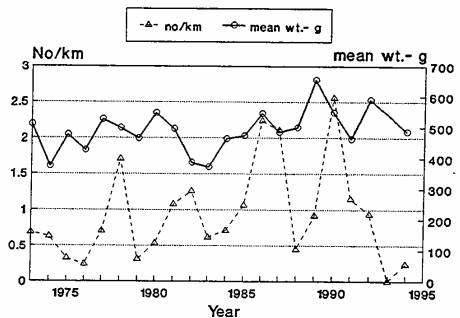
Figure 66: Mean annual catch (No\km) and mean weight of shortnose gar from 1968 through 1994.
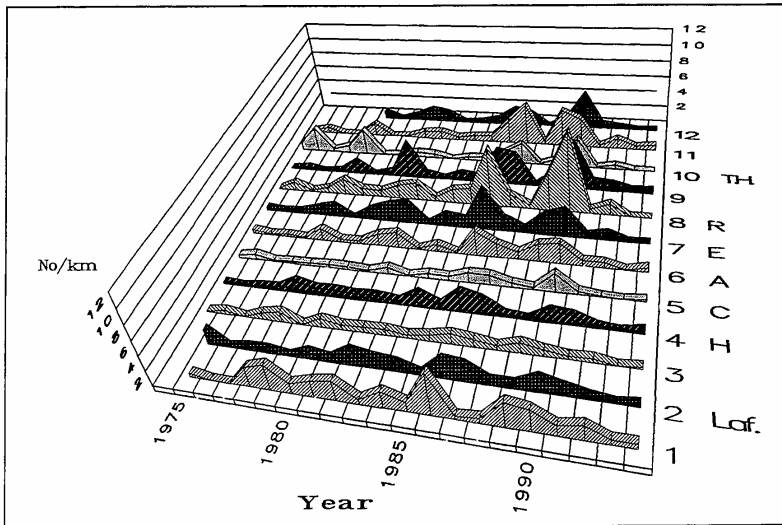
**Figure 67: Catch rates (No\km) of longnose gar
in 12 Reaches of the Wabash River from 1974 through 1994.**
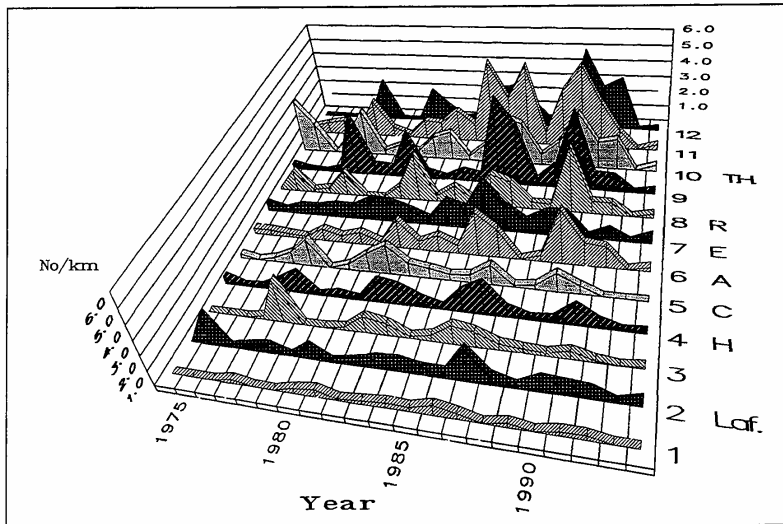
**Figure 68: Catch rates (No\km) of shortnose gar
in 12 Reaches of the Wabash River from 1974 through 1994.**
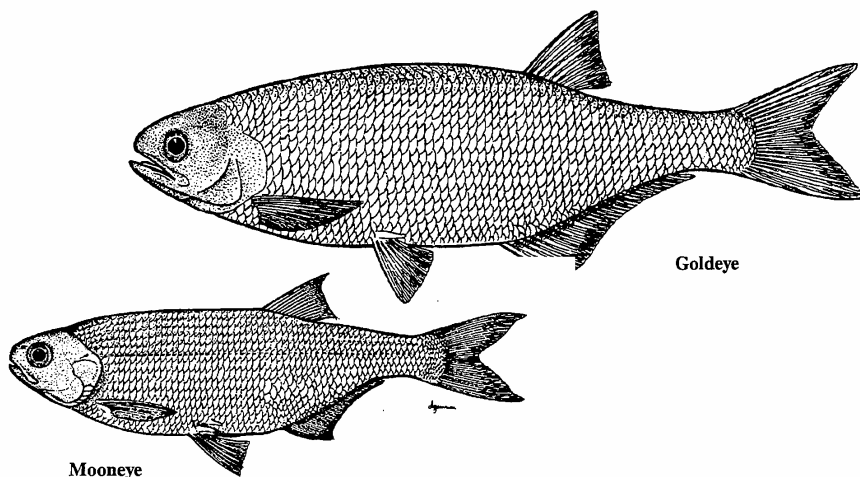
Goldeye - *Hiodon alosoides*
Mooneye - *Hiodon tergisus*

These two species are the only members of the family Hiodontidae, an ancient group restricted to North America. Their geographic range extends from the gulf of Mexico far north into Canada. Both species prefer larger streams, rivers, and lakes where they form schools. Their eyes are adapted to low light intensities and the goldeye is mainly nocturnal. Goldeye appear to be more tolerant of turbid waters than mooneye. Both species feed on a variety of invertebrates and small fish.

The average Wabash River goldeye is an impressive and beautiful fish weighing about 475 g (1 lb.), more than twice the weight of the average mooneye. They bite occasionally on live or artificial bait. Wabash River goldeye have been known to strike at small, surface lures. In Minnesota and

Canada smoked goldeye is commercially available.

Catches of goldeye increased considerably during the early and mid-1980's, but have declined to pre-1980 levels in recent years (Figure 69). However, the average size appears to have increased slightly since 1983. Until 1984 catches of goldeye outnumbered mooneye by a margin of nearly two-to-one. The post-1983 catch rate of mooneye increased ten-fold (Figure 70). Both the catch rate and average size of mooneye have declined since 1988.

Catches of goldeye were generally greater in the lower Reaches (Figure 71), while catches of mooneye have been higher in the upper Reaches (Figure 72), especially during the mid-1980's population boom.
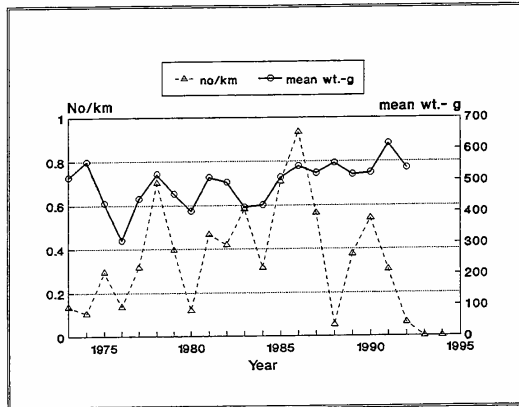
Figure 69: Mean annual catch (No\km) and mean weight
of goldeye from 1968 through 1994.
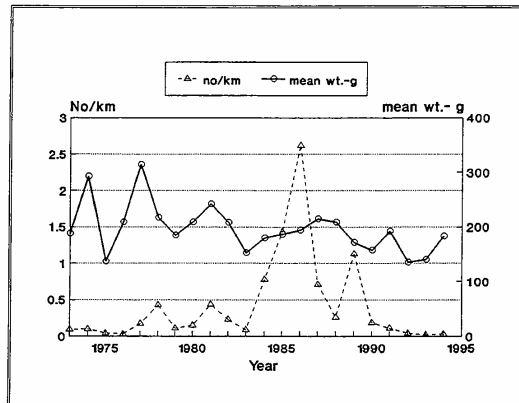
Figure 70: Mean annual catch (No\km) and mean weight
of mooneye from 1968 through 1994.

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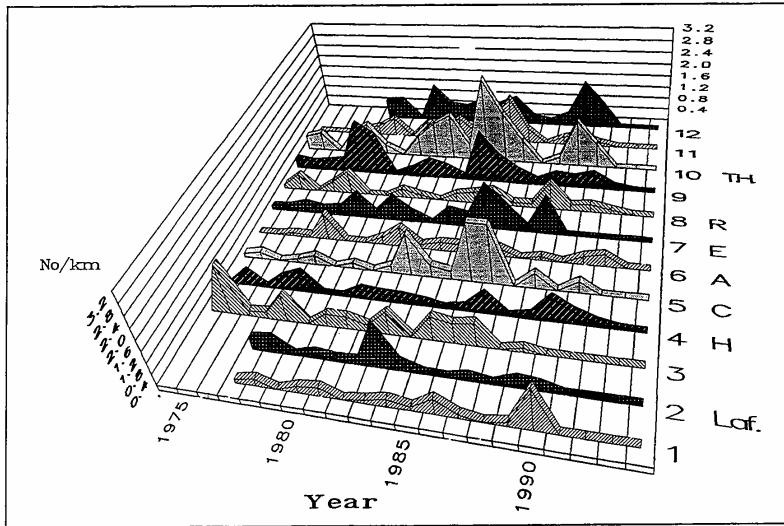
**Figure 71: Catch rates (No\km) of goldeye
in 12 Reaches of the Wabash River from 1974 through 1994.**
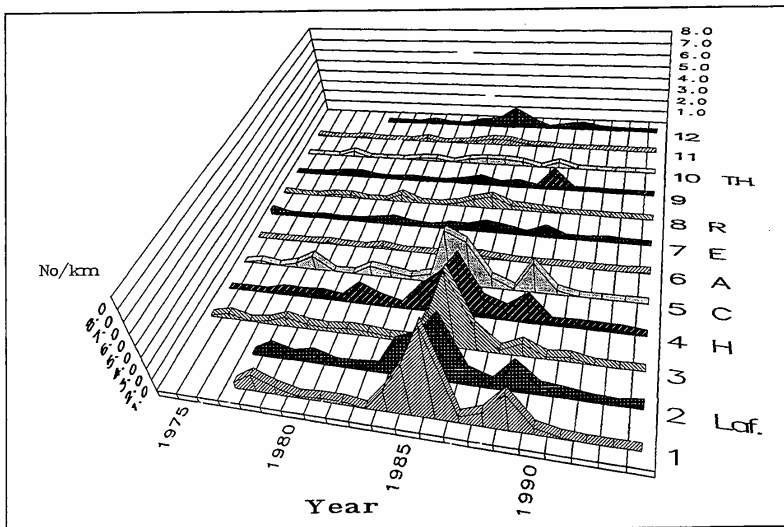
**Figure 72: Catch rates (No\km) of mooneye
in 12 Reaches of the Wabash River from 1974 through 1994.**
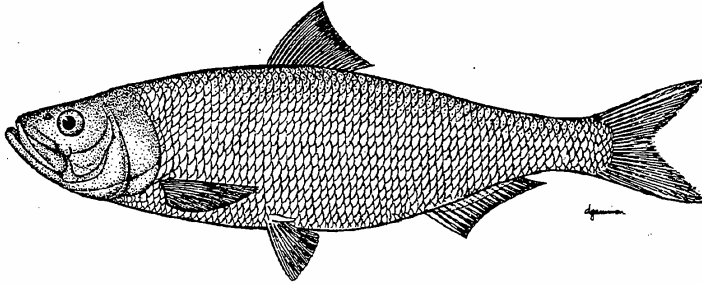
Skipjack Herring - *Alosa chrysochloris*

This relative of the gizzard shad is much less common in the Wabash River than it is in the Ohio River. It feeds primarily by sight on small minnows and aquatic insects. It is a mobile species and may undertake spring migrations. The larger individuals offer anglers good sport on light tackle, but the Wabash River population consists mainly of small fish. They are not a good food fish.

Catch rates over the years have been low except for sporadic increases (Figure 73). The average size of skipjack herring has increased about 50%, averaging about 150 grams before 1985 and about 225 grams thereafter.

Catches over the years have been limited, but quite evenly distributed throughout the 12 Reaches (Figure 74). Positive and negative changes in population density occurred throughout the study area.

The population of skipjack herring may be expanding slightly in recent years in Reach 11 downriver from Terre Haute, Indiana, but in other Reaches the population appears to be quite stable.
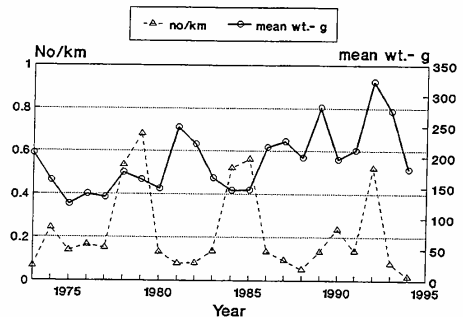
Figure 73: **Mean annual catch (No\km) and mean weight of skipjack herring from 1968 through 1994.**
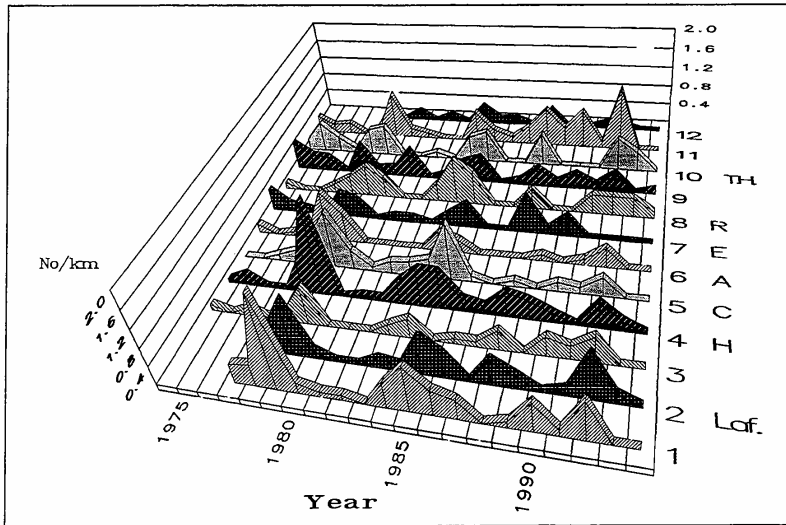
**Figure 74: Catch rates (No\km) of skipjack herring
in 12 Reaches of the Wabash River from 1974 through 1994.**
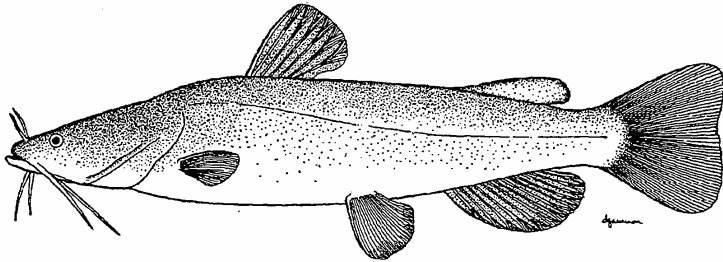
Flathead catfish - *Pylodictis olivaris*

This species ranks third numerically in electrofishing catches after gizzard shad and carp primarily because small flathead catfish are unusually susceptible to capture by the D.C. electrofisher. Most of the flathead catfish captured were small yearlings. Some larger individuals were taken, especially when the river was low, but not nearly in proportion to their abundance in the river.

Strong year classes were produced in 1978, 1982, and 1983 and large catches of yearlings were collected the following years (Figure 75). Electrofishing catch rates generally averaged from one to three fish per kilometer except for years with high numbers of yearlings. More larger individuals have been taken since 1985 with the result that the mean weight has increased significantly while numbers have remained relatively stable.

The enhanced thermal conditions after startup of the Cayuga EGS (Reach 6) in 1972 led to expanded populations of flathead catfish in this part of the river. The great preponderance of small flathead catfish continue to be taken at and downriver from that site. The flathead catfish population is mainly concentrated from Reach 6 (Cayuga EGS) downriver (Figure 76). They are one of the few species to be unusually abundant in Reach 8. There is also an indication of slight population increases upriver from the Cayuga EGS after its startup in 1971-72.

Flathead catfish is one of the few resident species which seems to be relatively unaffected by the 1993 flood.
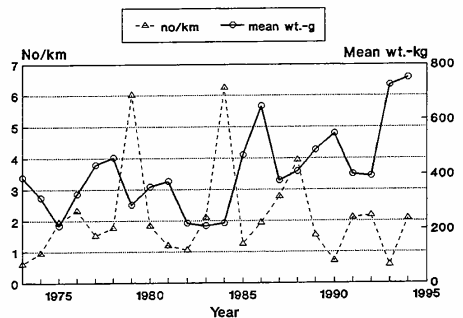
Figure 75: Mean annual catch (No/km) and mean weight of flathead catfish from 1968 through 1994.

Rud (1982) examined stomach contents of flathead catfish, most of which were fish three years old or less. Important food by weight included crayfish (42.4%), fish (23.7%), and aquatic insects (13.6%). Crayfish and fish become more important foods in older, larger specimens, while insect larvae were most important to younger fish. Other ichtalurids were frequently eaten by larger fish.

This species and channel catfish are the most sought after fish in the Wabash River. Trot lines are mostly employed by the casual angler, although there is some hook and line bait fishing. Commercial fishing is directed primarily at catfish with fishermen mostly using hoop nets. Flathead catfish harvest ranked second to channel catfish with catch rates increasing slightly between 1977 and 1986 (Glander 1984, 1987).
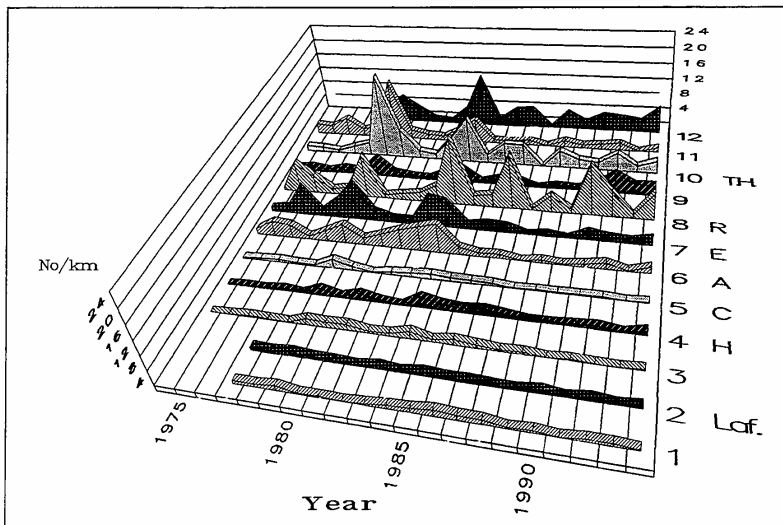
Figure 76: Catch rates (No\km) of flathead catfish
in 12 Reaches of the Wabash River from 1974 through 1994.
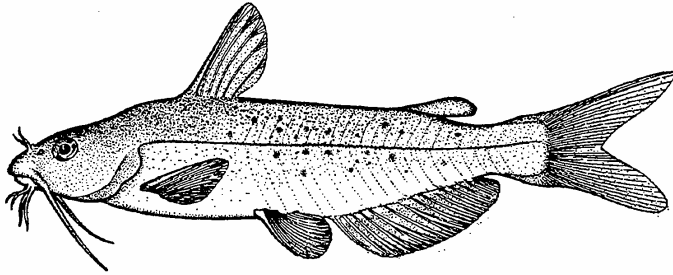
Channel catfish - *Ictalurus punctatus*

Channel catfish is a species which is not very susceptible to capture by electrofishing. Consequently, they have generally been taken in small numbers relative to their actual population abundance. It should be emphasized that they are much more abundant in the Wabash River than the catch rates would indicate. For many years they contributed little to the total catch. Catch rates were typically less than 0.5 fish per kilometer (Figure 77).

In 1984, however, they began to rise spectacularly to a maximum of about 8 catfish per kilometer in 1986. The actual population density of channel catfish at this time must have been very large and probably extended into tributaries as well as the mainstem of the Wabash River. This large increase apparently extended to the commercial harvest of channel catfish, because Glander (1984, 1987) found reported catches also increased strongly between 1977 and 1986.

The initial cause of this explosion of channel catfish, as with many other species,

was the exceptional spawning success enjoyed during the summer of 1983. The phenomenal increase and the effect it had on the size distribution of catches from 1984 through 1989 is shown in Figure 78. The 100 to 150 mm long progeny of the 1983 year-class shows clearly in the 1984 catch with only the usual smattering of larger catfish. They had grown to a size of 200 to 250 mm long fish by the summer of 1985 and there was also an
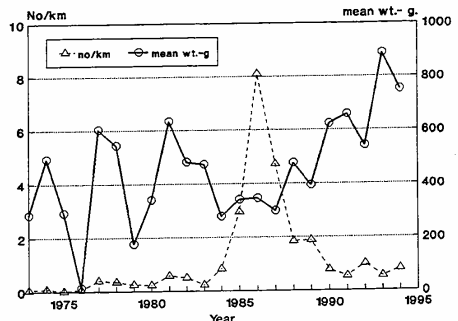
Figure 77: Mean annual catch (No\km) and mean weight of channel catfish from 1968 through 1994.

indication through the numbers of yearlings that spawning in 1984 had been successful. The large numbers of channel catfish generated by these two successive years of fruitfulness then lead to the enormous increase in catch of 200 to 400 mm long fish in 1986. The year 1987 was also a productive year for this species, but the population diminished gradually through 1988 and 1989 to return to more normal levels in 1990.

Catch rates have been stable since 1990, but the mean size continued to increase. The 1993 flood did not apparently adversely influence catch rates in 1993-94. However, the mean size of channel catfish was the highest on record, perhaps indicating reductions in smaller individuals.

Unlike flathead catfish, channel catfish are known to travel widely (Hubley 1963) and probably range throughout the mainstem and into tributaries. Nevertheless, the catch curves indicate somewhat greater concentrations of fish in Reaches 3, 4, 10, and 11 than in other Reaches (Figure 79). During the drought of 1988, however, much larger catches were made in Reaches 1 through 4 than in the lower Reaches.

Channel catfish were found to eat many different kinds of foods in the study by Rud (1983). Most of the food biomass consisted of fish (54.6%), crayfish (34.6%), and aquatic insects (1.2%). However, the fish component included a large amount of fish eggs.
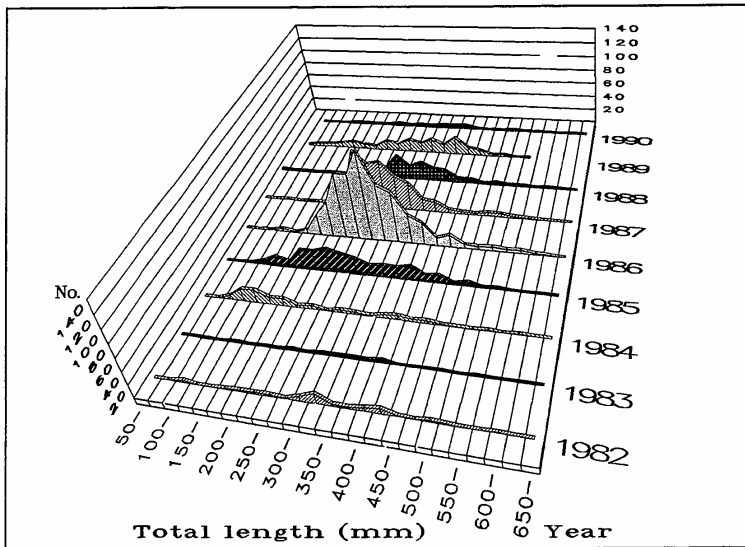
Figure 78: Size distribution of channel catfish from 1982 through 1990 showing the success of the 1983-84 year classes.
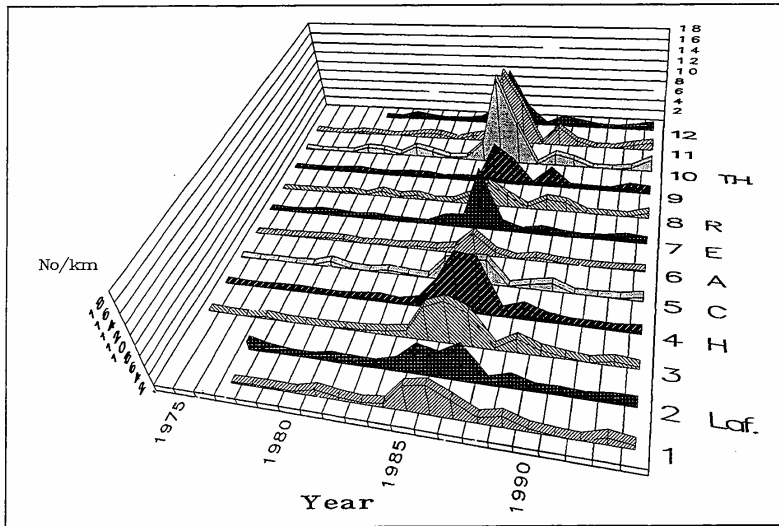
**Figure 79: Catch rates (No\km) of channel catfish
in 12 Reaches of the Wabash River from 1974 through 1994.**
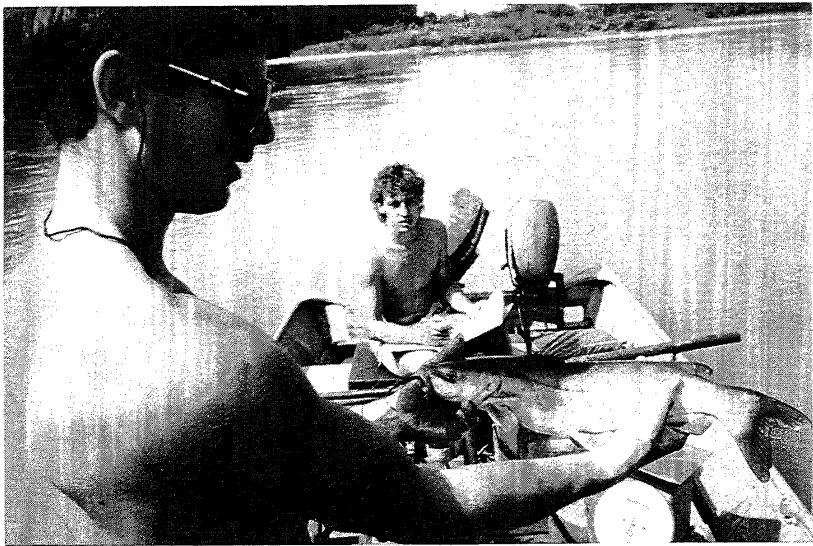
Todd Sellers and Greg Seketa record a typical Wabash River channel catfish.
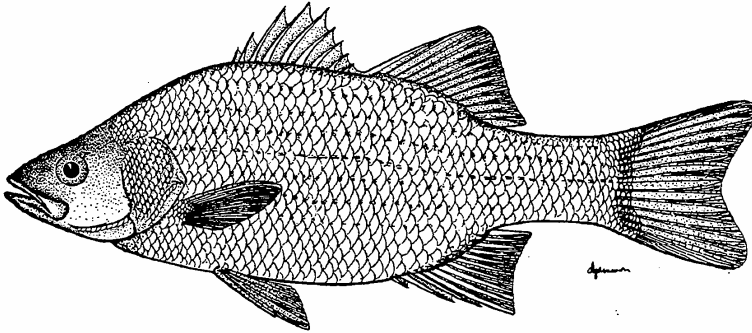
White Bass - *Morone chrysops*

The white bass is the most common member of the "temperate basses" found in the Wabash River. Its close relative is the smaller yellow bass *(Morone mississippiensis)*, which also occurs in small numbers. Both species have dark, longitudinal stripes along their sides which are continuous in the white bass, but discontinuous above the anal fin in the yellow bass.

A third member of this family has appeared in the Wabash River in recent years, a hybrid striped bass x white bass (*M. saxatilis* x *M. chrysops*) sometimes called a "wiper", sunshine bass, or palmetto bass. The Indiana Department of Natural Resources stocks this hybrid regularly in reservoirs as a trophy fish. Hybrid striped bass feed voraciously, grow fast, and have excellent fighting qualities.

The population sources of most of the white bass in the Wabash River are probably nearby reservoirs: Huntington, Salamonie,

Mississinewa, Freeman, Shaffer, and Mansfield. This species prefers clear water in larger rivers, reservoirs, and lakes. Schools of white bass roam near the surface feeding on small fishes, zooplankton, and insects and are most active in early morning and late evening. In the Wabash River white bass
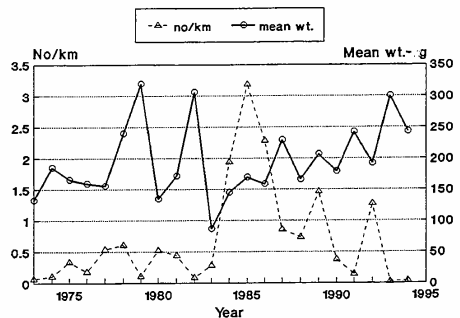
Figure 80: Mean annual catch (No\km) and mean weight of white bass from 1968 through 1994.

prefer the quiet, sandy bottom areas on the insides of river bends.

During the spring white bass migrate from reservoirs into tributaries feeding into them to spawn. After these spring "runs" most of the fish return downstream to the reservoirs. It is likely that many white bass in the Wabash River originate from reservoirs and are carried into the Wabash River during the periodic drawdowns which stabilize reservoir water levels. White bass are a popular fish to catch and eat.

Three-quarters of white bass stomachs examined by Rud (1982) contained aquatic insect larvae, 75% of which were Ephemeroptera and Trichoptera. Fifty-nine percent contained fish, which made up nearly half the

weight of food consumed. Seventeen percent of the fish had eaten a wide variety of crustaceans.

Electrofishing catches of white bass exhibited the characteristic increase following 1983, peaking in 1985 and then declining thereafter (Figure 80). As many individuals were captured from 1984 through 1986 as had been caught during the previous decade. After 1986 the catches everywhere gradually declined until they had returned to "normal" levels of abundance by 1990.

The upper six Reaches generally yielded more white bass than the lower six Reaches (Figure 81). Very few white bass were taken after the 1993 flood.
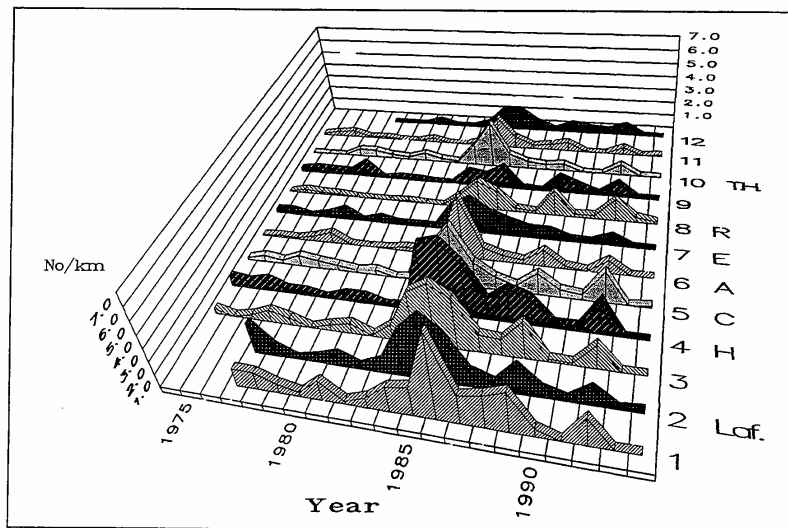
Figure 81: Catch rates (No\km) of white bass
in 12 Reaches of the Wabash River from 1974 through 1994.

If the reservoir populations of white bass are the primary source of the fish found in the Wabash River, what factors are responsible for the dramatic increase in the white bass population of the river after 1983? White bass abundance might merely be a function of how frequently the reservoirs are drained. Another possibility is that environmental conditions in the Wabash River itself have been conducive to a thriving existance only in recent years. Whatever the reason or reasons, the population boom appears to be over and reestablishing the population may require some years of more stable flows.
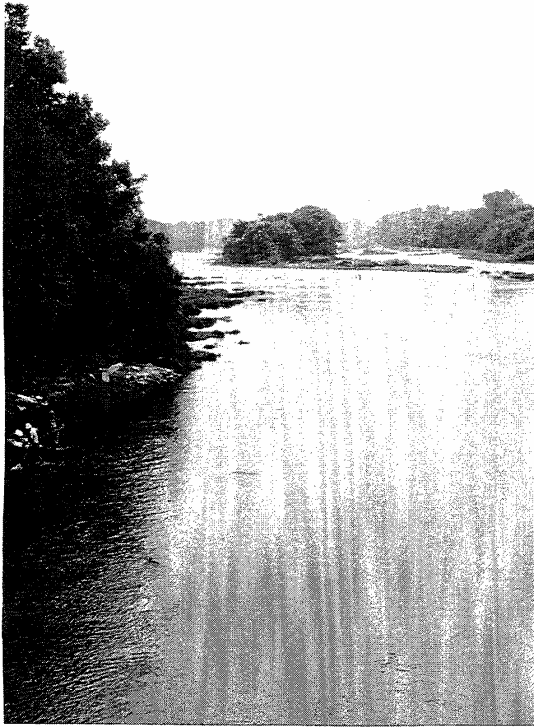
The Wabash River at Logansport, Indiana.

Mike Stroup and Dave Petree relax while traveling to the takeout.
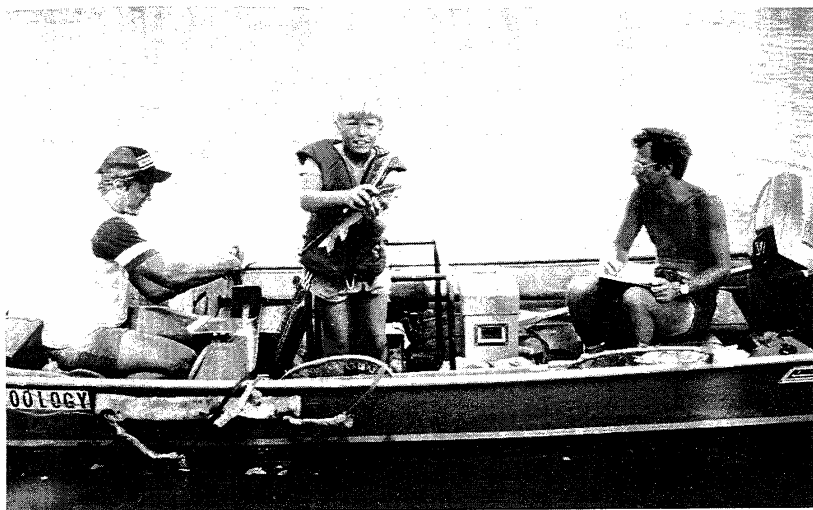
Ed Snizek weighs and measures, Brad Garner releases, and John Riggs records.
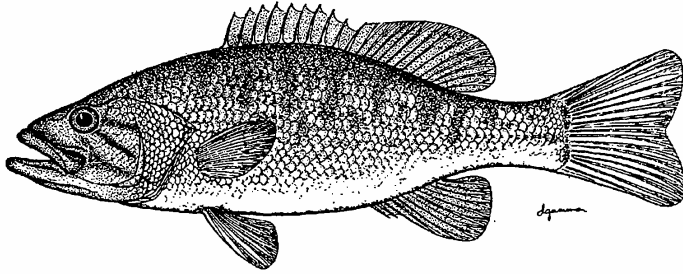
Smallmouth Bass - *Micropterus dolomieui*
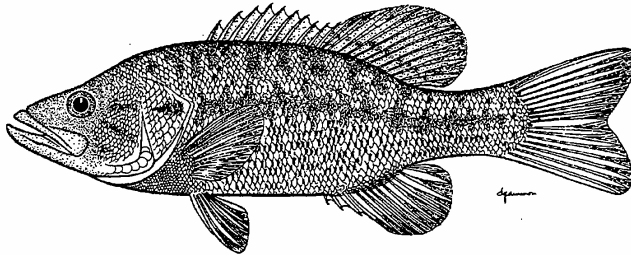
Spotted Bass - *Micropterus punctulatus*
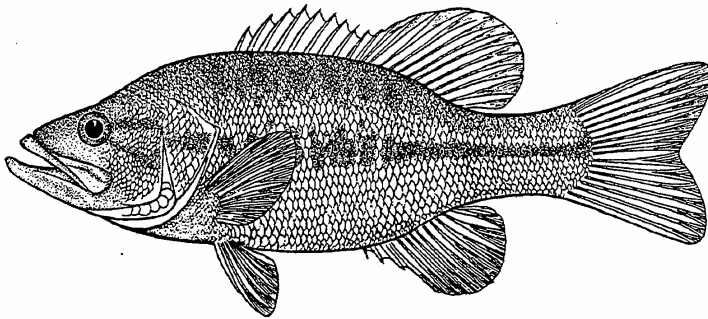
Largemouth Bass - *Micropterus salmoides*

Smallmouth bass - *Micropterus dolomieui*
Spotted bass - *Micropterus punctulatus*
Largemouth bass - *Micropterus salmoides*

The smallmouth bass is one of the finest sport fish to be found anywhere. In the Wabash River system it is abundant today only in smaller clear, clean tributaries to the Wabash River, although it once occurred in abundance throughout most of Indiana's rivers. Water quality improvements may be benefitting smallmouth populations of both the White River and the Wabash River, as will be discussed.

The life cycle of smallmouth bass begins with spawning in the spring when the water temperature reaches about 16°C (60° F). Males build a small nest in gravel and fertilize the eggs deposited by several females. He then guards the nest and drives away intruders. Normally, the small fry hatch within a week and remain in the nest for a few days before scattering throughout the stream. The jet black fry feed on small invertebrates, growing rapidly and gradually turning brown in coloration.

Smallmouth bass may spawn several times each summer. Juveniles grow to a length of 50 to 75 mm (2 to 3 inches) by fall, feeding primarily on small invertebrates. They grow to 150 to 200 mm (6 to 8 inches) by the second year and include more and more crayfish and fish in their diets. By the end of the third year of life they typically reach total lengths of 225 to 275 mm (6 to 11 inches) and will be ready to spawn the next spring.

Catch rates of smallmouth bass were usually low, about 0.1 to 0.2 fish per kilometer, except for the years immediately after the low-flow summers of 1988 and 1991

and for three years after 1983 (Figure 82). Young smallmouth bass hatched in 1983 entered the Wabash River by 1984 and remained there for at least three more years. During that period the size of smallmouth steadily increased (Figure 83).

Other than the peak years, smallmouth bass were usually found close to the mouths of tributaries. The catch pattern of smallmouth bass over the period of study was very similar to that of mooneye with the greatest expansion of the population occurring in the upper four Reaches (Figure 84).

Rud (1982) examined only 16 smallmouth bass stomachs, mostly one- and four-year-old fish. Crayfish were found in about two-thirds of stomachs containing food, while insect larvae occurred in half the stomachs. Fish made up a negligible part of their diet.
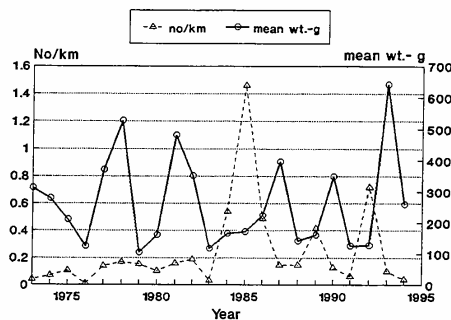
Figure 82: Mean annual catch (No\km) and mean weight of smallmouth bass from 1968 through 1994.
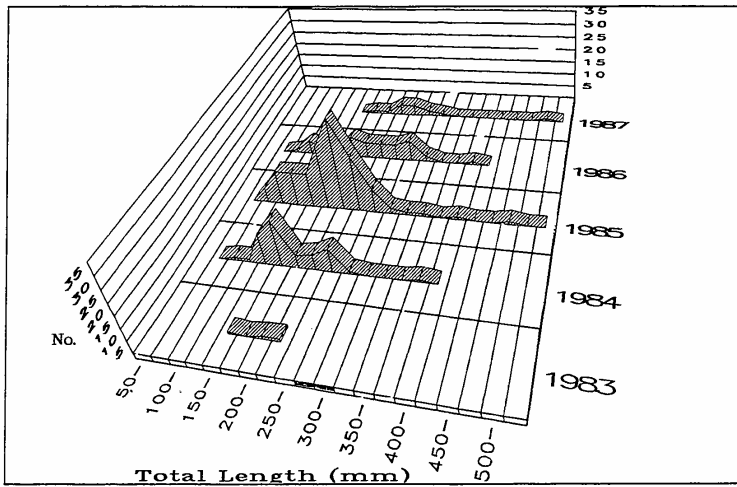
Figure 83: Length frequency of smallmouth bass from 1983 through 1987.
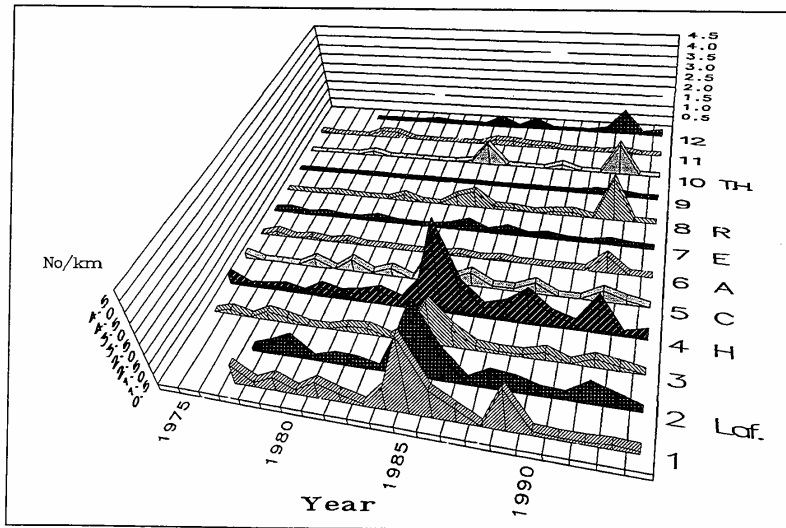
**Figure 84: Catch rates No\kg) of smallmouth bass
in 12 Reaches of the Wabash River from 1974 through 1994.**

Many rivers and streams in central and southern Indiana contain spotted bass, although most fishermen might not recognize them. On the northern fringe of their geographic range here, they grow slowly and seldom reach 300 millimeters in length (12 inches). Physical characteristics are somewhat intermediate between smallmouth and largemouth bass. They possess the head and smaller mouth of the former, but the general coloration of the latter although they usually have linear rows of spots below the broad dark band along the lower flanks.

Catch rates of spotted bass exhibited the same basic pattern as for smallmouth bass (Figure 85). The catch rate never exceeded 0.2 fish per kilometer until after 1985 and peaked in 1986, 1989, and 1992, again following summers of low-flow. The average weight was usually less than about 300 grams (0.66 lbs).

The distribution of spotted bass within the middle Wabash River changed considerably during the period of investigation. Prior to about 1980 nearly all specimens were found in the lower Reaches south of Covington, Indiana (Figure 86). Over the next decade they moved northward to Lafayette, to Delphi, and then continued on upriver. In 1990 we found that this species was widely distributed in the Eel River system (Gammon and Gammon 1990, 1993).

As with some other species, the catch rate increased in the lower as well as the upper Reaches, with a particularly large increase in Reach 12 south of Darwin, Illinois. This dramatic increase, in particular, may be indicative of a genuine improvement in water quality of the lower Wabash River. The avoidance of thermally unacceptable

areas (Reaches 6 and 9) is approximately the same order of magnitude as for smallmouth bass.

It appears that both smallmouth and spotted bass populations were again expanding in 1992, but the flood of 1993 severely reduced the numbers of both species.

About half of the 36 spotted bass stomachs examined by Rud (1982) contained crayfish. Aquatic insect larvae were found in 39% of the stomachs, while fish were found in 30%.

Only a few individuals of largemouth bass were collected each year. These probably entered the Wabash River via tributaries and originated from populations both in reservoirs and farm ponds. The middle Wabash River lacks weedy backwater areas which would be the preferred habitat of this species.
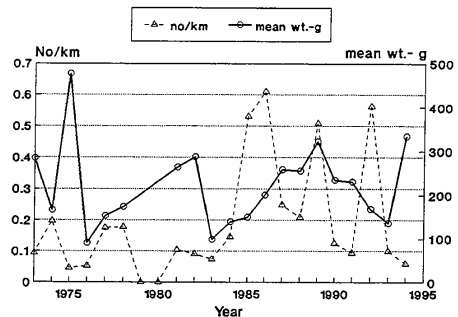
Figure 85: Mean annual catch (No\km) and mean weight of spotted bass from 1968 through 1994.
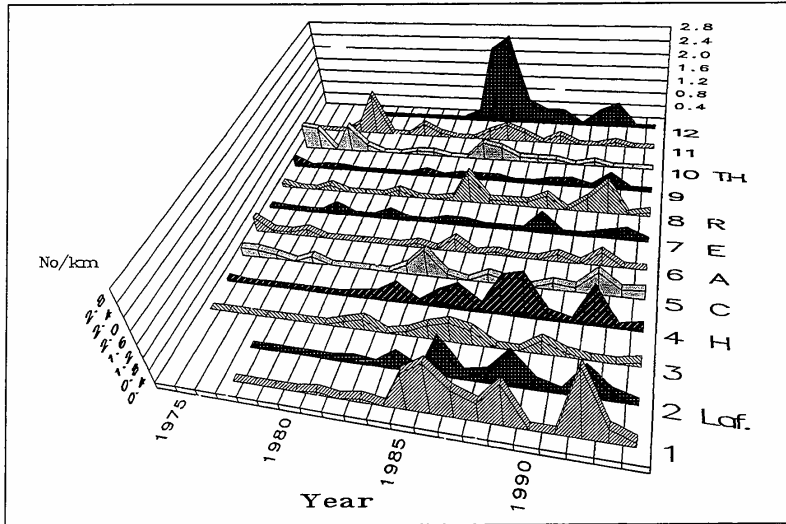
**Figure 86: Catch rates (No\km) of spotted bass
in 12 Reaches of the Wabash River from 1974 through 1994.**
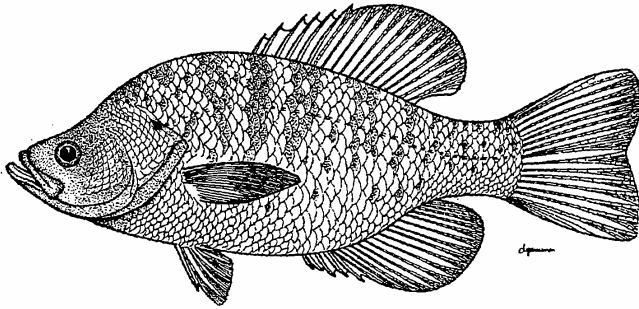
White Crappie - *Pomoxis annularis*
Black Crappie - *Pomoxis nigromaculatus*

Both species of crappie are widely distributed in Indiana streams, rivers, reservoirs, and lakes. Both species prefer quiet waters near some kind of subsurface cover. White crappie are more tolerant to turbid waters than black crappie and perhaps this is why they are nearly ten times more abundant in the rivers and streams of westcentral Indiana.

Neither species is very abundant in the Wabash River, but they are a regular component of the electrofishing catch. More than 85% of crappie taken from the Wabash River consist of white crappie which is drawn above.

Annual catches were low and changed little over the period of study (Figure 87). Reaches 1 and 5 were most consistent producers of crappie, but crappie were nearly as common downriver from Terre Haute,

Indiana. Catches from Reaches 6, 7, 8, and 9 were consistently lower than elsewhere. The population increases experienced by many species from 1985 through 1987 were barely evident for crappie.

Rud (1982) examined 39 white crappie stomachs and found that 53% contained fish, primarily gizzard shad, and 93% yielded insect larvae, primarily Trichoptera (caddis flies).

Ten black crappie stomachs were examined. Their contents consisted principally of aquatic insect larvae, mostly Trichoptera. However, nearly 65% of the weight of recovered food consisted of fish, mostly centrarchids.
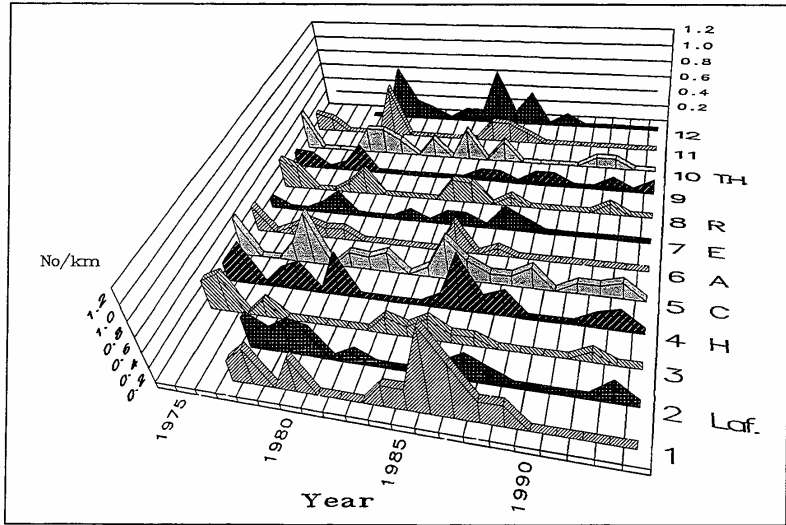
Figure 87: Catch rates (No\km) of white and black crappie in 12 Reaches of the Wabash River from 1974 through 1993.
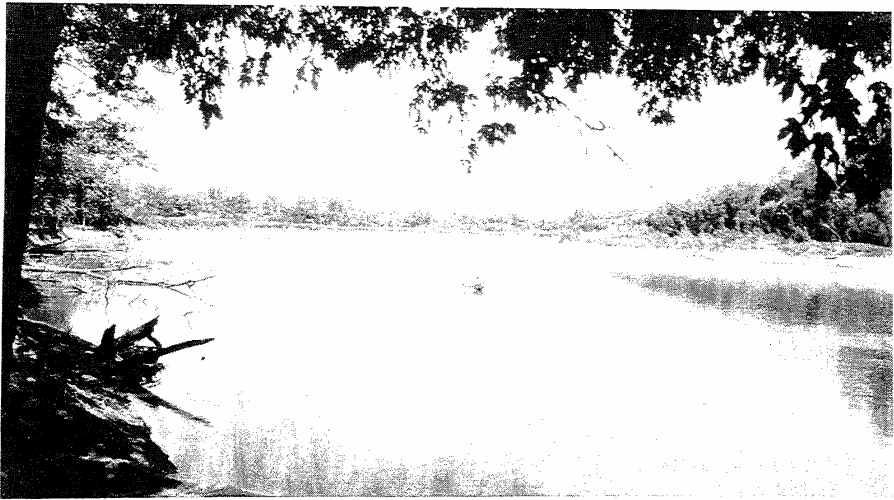
The Wabash River north of the Cayuga Electric Generating Station during the drought of 1988.

Longear Sunfish - *Lepomis megalotis*

The longear sunfish is much more abundant in small and medium-sized streams than it is in the Wabash River. However, it was a regular component of the annual catches, but only in the upper five Reaches (Figure 88). The overall pattern of catch rates indicates a fairly strong negative effect in and downstream from Lafayette (Reaches 2 and 3), then a recovery followed by reduction to near zero at the Cayuga EGS (Reach 6). This species is virtually absent in the main river downriver from the Cayuga EGS. Longear sunfish exhibited a mild increase in abundance during 1985-86.
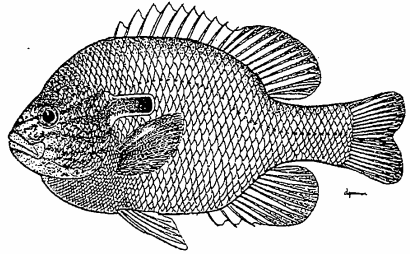
Rud (1982) found that longear sunfish, mostly two- and three-year olds, fed primarily upon aquatic insects, especially Diptera and Trichoptera larvae followed by Ephemeroptera larvae. Crayfish were also present in 24% of the fish.
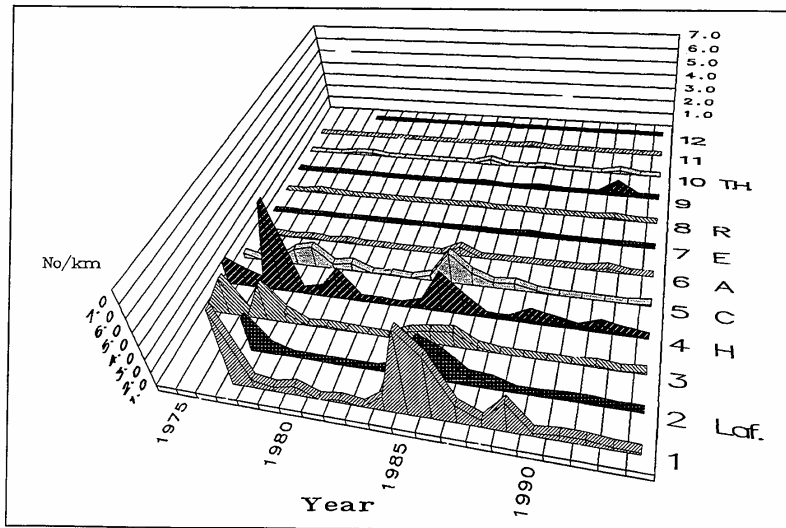
Figure 88: Catch rates (No\km) of longear sunfish in 12 Reaches of the Wabash River from 1974 through 1994.
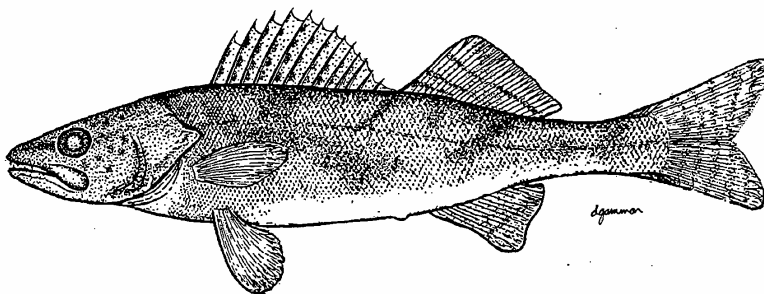
Sauger - *Stizostedion canadense*

The sauger maintains a low, but persistent population in the Wabash River. It is similar in basic appearance to its close relative the walleye (*Stizostedion vitreum*) but, unlike walleye, it has spots between the rays of the spinous dorsal fin.

Sauger are currently caught only occasionally by anglers usually while fishing for other species such as channel catfish. In the Ohio and Mississippi Rivers sauger are important sport fish. It could become an equally important asset of the Wabash River in the future if the river can be further improved in environmental quality.

The sauger is more tolerant of turbid water than the walleye, perhaps because they tend to feed during the daylight hours rather than at night as with walleye. They prefer swifter, deeper water than walleye and feed in deeper water than walleye.

The sauger population has exhibited great variability in abundance and average weight (Figure 89). Until 1977 catch rates were variable and averaged about 0.4/km. The average weight increased steadily from about 400 grams to about 700 grams. Between 1977 and 1984 catch rates were very low and consisted mostly of large individuals weighing an average of 800 to 900 grams. As with other species the catch rate increased markedly to 0.7 fish per kilometer from 1985 through 1987 and then declined to about 0.3 fish per kilometer since 1988. The weight has averaged about 600 grams (1.3 lbs) since 1983. The 1993 flood may have had an inverse impact on the sauger population.
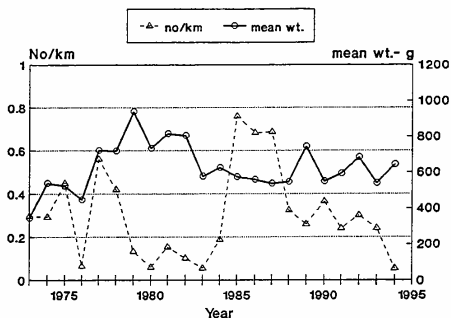
Figure 89: Mean annual catch (No\km) and mean weight of sauger from 1968 through 1994.

Catch rates have been much higher in Reaches 1 through 4 than they were in Reaches 6 through 9. Reach 5 appears to be a stretch of river with catches of an intermediate size. Sauger are about as thermally sensitive as redhorse and few are found downriver from the Cayuga or Wabash River electric generating stations. Sauger were scarce in Reaches 7 and 8 and were nearly absent from the Terre Haute, Indiana area and downriver until the mid-1980s.

The population increases of 1985-87 were most prominent in the upper four Reaches, but there was also an encouraging increase in catch rates in the lower three Reaches as well. The 1994 sauger population is currently at a low level of abundance, as low as it was in the late 1970s and early 1980s. This species has shown itself capable of rapid population growth, however, and it is hoped that it will soon rebound again.

Rud (1982) examined stomachs from 86 sauger, mostly four-year-olds, and found fish remains in all of them. Fish constituted more than 95% of the diet. Nearly 30% of food eaten were centrarchids, including centrarchid bass, followed by cyprinids (11% by weight) and white bass (11%). Neither gizzard shad nor catfish species were important food items.
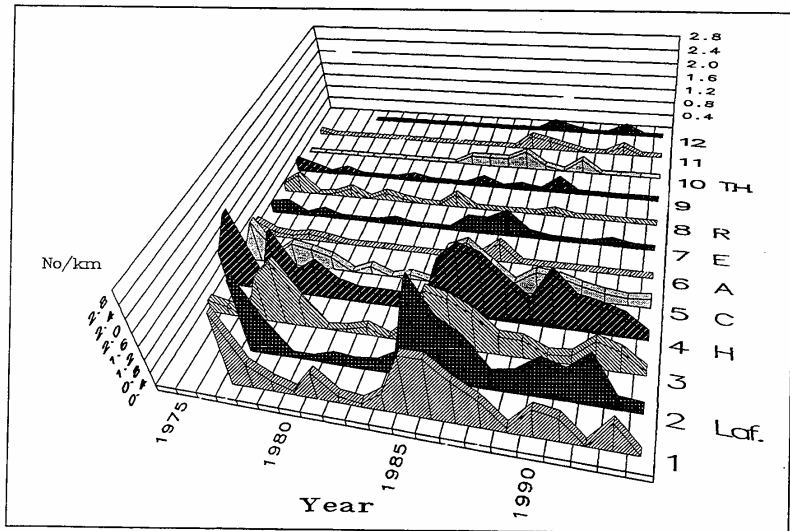
Figure 90: Catch rates (No\km) of sauger
in 12 Reaches of the Wabash River from 1974 through 1994.
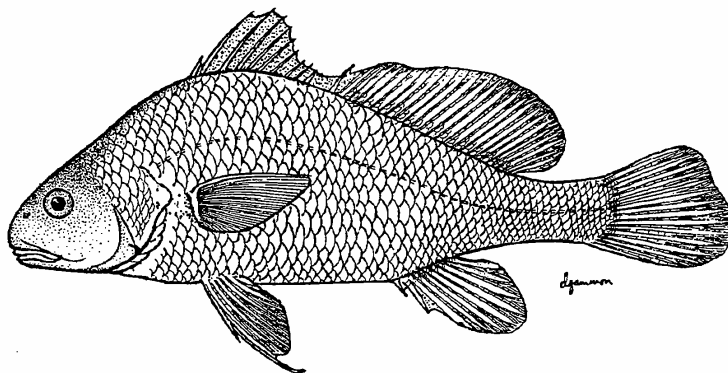
Freshwater Drum - *Aplodinotus grunniens*

This unusual species is better known to hoosier fishermen as the "white perch". Farther north it is called "sheephead". It is the only freshwater member of a family of fish which is otherwise entirely marine. The males have the interesting ability to generate sound by means of a muscle stroking its air bladder during the spring reproduction season (Schneider and Hasler 1960).

The head contains large otoliths or earbones which have a L-shaped mark on one of the two flat surfaces. These "Lucky" stones are sometimes collected by fishermen when the fish is cleaned and carried to foster good luck.

The drum is a large, handsome fish with a gray back, steely silver sides, and a white belly. The lateral line extends to the rounded rear edge of its caudal fin (tailfin). Drum are long lived and may exceed 15 kg (30 lbs) in weight. However, the mean weight in the Wabash River is less than 1 kg (2 lbs). It is taken by angling with live bait, but it is only a fair food fish with soft flesh.

A remarkable change in population abundance of drum has occurred during the period of study (Figure 91). Prior to 1985 the mean catch rate of drum rarely exceeded 0.5 fish per kilometer. In 1985 it increased to 1.0 fish/km and increased further to plateau at about 1.5 fish/km since 1986. The average weight has oscillated between 400 and 800 grams (1 - 2 lbs) since 1973.
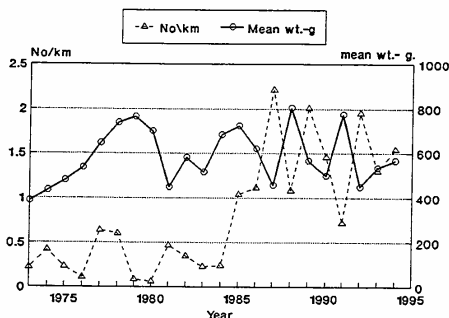
Figure 91: Mean annual catch (No\km) and mean weight of freshwater drum from 1968 through 1994.

The increased population levels of drum since 1985 include all Reaches of the Wabash River (Figure 92). Only a modest expansion resulted in the immediate vicinity of Reach 6 (Cayuga Electric Generating Station), but catches in Reach 9 (Wabash Electric Generating Station) were nearly as great as in flanking Reaches.

Catches of drum in the lower Reaches were sharply lower during the 1988 and 1991 droughts, but since then they have increased even more in the lower Reaches while holding fairly steady in the upper five Reaches.

Electrofishing catches taken immediately after the 1993 flood and also in 1994 indicate that drum were impacted little or none by the 1993 flood.

Most of the drum whose stomachs were examined by Rud (1982) were 4- and 5-year-old fish which principally fed upon insect larvae, notably Ephemeroptera. Freshwater drum are generally believed to eat molluscs which they grind with heavy pharyngeal teeth. However, clams and snails made up only 10% of the weight of food found in stomachs, while fish comprised another 10%.
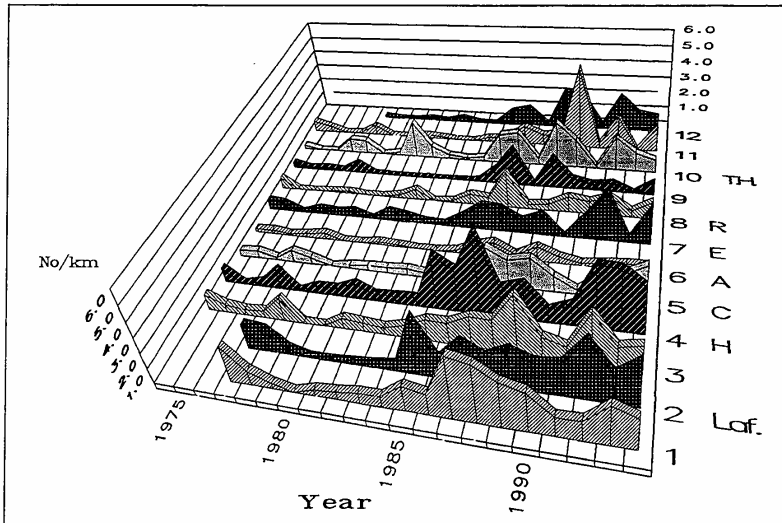
Figure 92: Catch rates (No\km) of freshwater drum
in 12 Reaches of the Wabash River from 1974 through 1994.
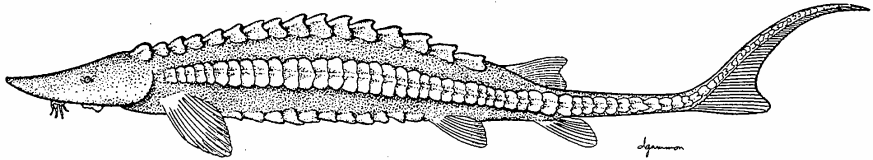
Shovelnose Sturgeon - *Scaphirhynchus platorynchus*

The shovelnose sturgeon is fairly common and widely distributed in the Wabash River. However, they are not very susceptible to collection by electrofishing for the same reason as blue sucker; they are most prevalent on the bottom of fast, deep chutes. Moving close to the bottom with barbels brushing the surface of the gravel, sturgeon "tastes" for food items which then are sucked up with the vacuum-cleaner mouth.

Electrofishing catches of sturgeon are strongly influenced by water level. When river discharge is strong the water is generally too deep for effective electrofishing. For example, no sturgeon were collected during the period of high summer discharge from 1979 through 1981. Catch rates improved during summers with relatively low discharge rates.

Our catches of this small sturgeon generally consisted of single individuals from 700 to 900 mm in length and weighing 1 to 2 kg. They contribute a minor part of the commercial catch on the Wabash River (Glander 1984, 1987). Overall, the abundance of sturgeon has increased over time and the average size also seems to have

increased since 1982 (Figure 93).

The distribution of sturgeon appears to be almost discontinuous (Figure 94). No sturgeon were collected from Reaches 4 and 10 until 1992 and 1993. They are very rare in Reach 6 at the Cayuga EGS, although good catches have been taken recently in Reach 9 at the Wabash River Electric Generating Station. Populations seem to have increased, however, in all the other Reaches since about 1982.
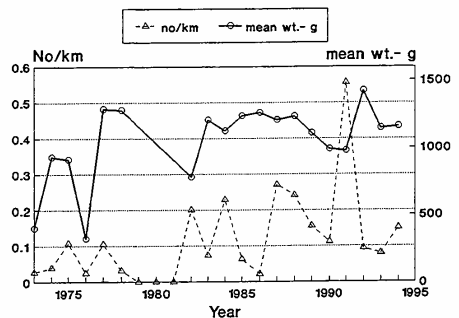
Figure 93: Mean annual catch (No\km) and mean weight of shovelnose sturgeon from 1968 through 1994.
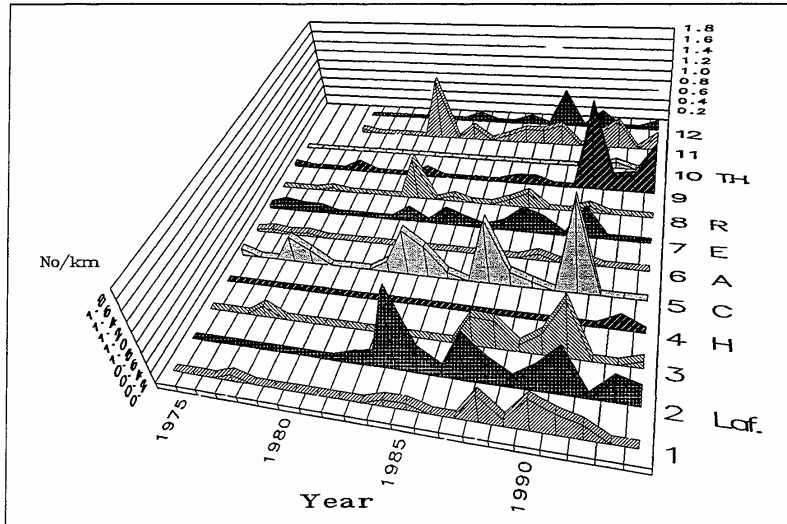
**Figure 94: Catch rates (No\km) of shovelnose sturgeon
in 12 Reaches of the Wabash River from 1974 through 1994.**
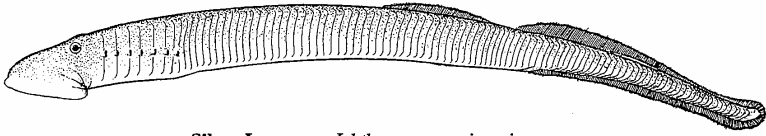
Silver Lamprey - *Ichthyomyzon unicuspis*
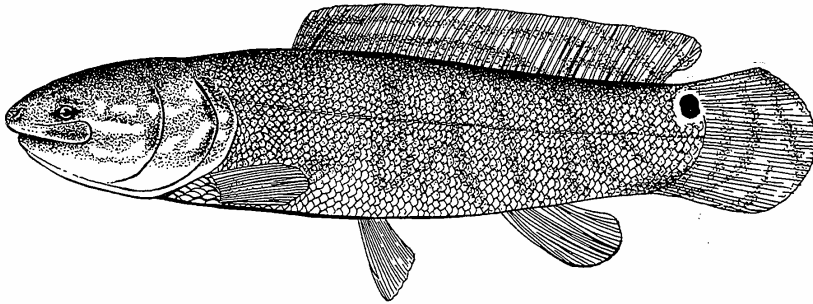
Bowfin - *Amia calva*
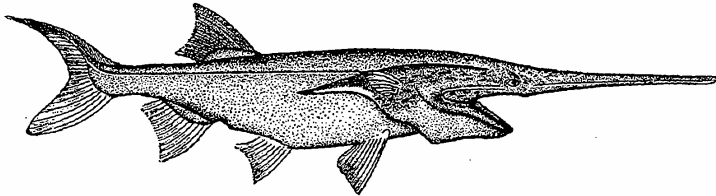
Paddlefish - *Polyodon spathula*
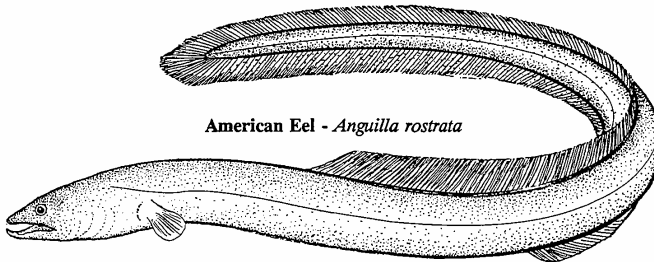
American Eel - *Anguilla rostrata*

Other Species of Fish

The preceeding discussions include only the more common and important species of fish inhabiting the Wabash River. Many other interesting species also reside in the river (Table 5), but they were captured in insufficient numbers to provide adequate information about their relative population abundance over time or their distribution within the middle Wabash River.

Many species of minnows were collected, but only in small numbers relative to their actual population size for two reasons: (1) the relatively fast water habitats designated as collecting sites are not favored locations and (2) the bias of the electrofishing apparatus against collecting smaller fish. During special studies when a seine was employed for collecting a great many species of minnows and other fishes were collected together with numerous young-of-the-year of larger species.

One larger species of minnow which regularly appeared in the catches from the upper Reaches was the silver chub (*Macrhybopsis storeriana*). This species inhabited not only the mainstem of the Wabash River, but also the lower courses of its larger tributaries such as Sugar Creek (Gammon et al. 1991). Other common residents of the upper Reaches included the rock bass (*Ambloplites rupestris*), the bluegill (*Lepomis macrochirus*), and the log perch (*Percina caprodes*).

Most other larger species were caught only sporadically and it was not possible to determine if they preferred one part of the river more than another. From 1968 through 1994 a total of 78 American eel (*Anguilla rostrata*), 18 paddlefish (*Polyodon spathula*), 119 bowfin (*Amia calva*), 218 silver lamprey (*Ichthyomyzon unicuspis*), several blue catfish (*Ictalurus furcatus*), 2 burbot or freshwater cod (*Lota lota*), and a goldfish (*Carassius auratus*) were collected. None of these species is important ecologically, but each is interesting and some have extremely fascinating life histories.

The American eel, for example, were all large, immature fish. This species is largely nocturnal and feed upon dead and live fish and crayfish. They can exist in waters too polluted even for carp.

After living several years in the Wabash River they migrate into the Ohio River, then the Mississippi River and ultimately into the Gulf of Mexico, if they are fortunate. They must then move to their reproductive grounds, once thought to be the Sargasso Sea, but more recently believed to be south of the Bahama Islands (Vladykov 1964). Spawning occurs from late winter to early spring and the adults presumably die after spawning. The floating eggs hatch into planktonic larvae which are carried northward by the gulf stream toward North America and Europe. Eventually the growing eels reenter the Mississippi River and migrate northward to its tributaries, including the Wabash River, negotiating several dams in the process.

Most other species mentioned are life-time residents of the Wabash River and all of them possess special attributes which have enabled them to successfully maintain their presence for hundreds of years, despite the great changes in environmental conditions which have occurred over time.

The Walleye, also known as walleyed pike, pikeperch, or jack salmon, was once abundantly present in the Wabash River. Descriptions of spring spawning runs into some of its larger tributaries indicate a large population of large fish were present at least into the early 1800's. However, the walleye was absent from the Wabash River and its tributaries until recently. It has survived in small numbers in the Ohio River, but Pearson and Krumholz (1984) indicate that it appears to be diminishing in numbers in recent decades.

We captured very few walleye until about 1985, after which they became a small, but regular component of the electrofishing catch. Their appearance can be traced to Indiana Department of Natural Resources program of raising walleye in fish hatcheries and stocking most of Indiana's reservoirs.

Some of the stocked walleye escape and enter tributaries and eventually the Wabash River itself.

Walleye are rare during summer near the Cayuga and Wabash River electric generating stations because they are among the more thermally sensitive species. They are also rare in Reaches 8, 10, 11, and 12. However, they do appear occasionally in other segments of the river. As indicated previously, walleye are nocturnal fish which feed mainly in the evening, night, and early morning. The sauger, on the other hand, feeds primarily during the day. The turbidity of the Wabash River would make food location difficult for both species, but especially the walleye. Should the turbidity of the Wabash River be reduced in the future the walleye could once again become an important species.

COMMUNITY INDICES BASED ON ELECTROFISHING CATCHES

The foregoing discussion of patterns of relative abundance of important individual fish species indicates that most species populations of the Wabash River are highly variable over time and space. Basing environmental evaluations on all important species is a difficult task. Biotic communities are usually dominated by a few species with many others represented by a few individuals.

The complexities of both the biotic and environmental components of nature are such that most ecologists have attempted to find some magical "Golden Fleece" to simplify the interpretation process. Some ecological studies have attempted to reduce and simplify systems by designating some species as representative "indicator" species which reflect the tolerance and attributes of the entire community in some way.

Many other studies have sought ways to represent quantitatively the entire or some important part of the community (Pielou 1977, 1984; Ludwig and Reynolds 1988). The development of the composite index of well-being or Iwb described previously was partly motivated by the need to simplify data. Twenty-five years ago we endeavored to develop both a collecting protocol and methods for analyzing the resulting data for purposes of evaluating the environmental impact of electric generating stations (Gammon 1971, 1973, 1976). The environmental criteria which were being established at that time were to institute physical and chemical levels which would provide protection for resident aquatic biota.

The electric power industry sought and received from regulatory authorities an exemption from thermal limits if it could be shown that a healthy population of aquatic organisms lived in heated waters produced by generating plants. To achieve this exemption it had to be shown through the so-called 312(a) demonstration that the aquatic communities immediately downriver from electric generating plants were both diverse and numerous. In other words, it was necessary to demonstrate that the biotic integrity of the community was maintained despite excursions of temperature beyond the established criteria.

We examined several quantitative expressions of biotic diversity, including the number of species and the Shannon-Weiner or Shannon-Weaver index of diversity for their utility in evaluating the impact of electric power plants. Quantitative expressions of abundance commonly used in population work were also examined for their usefulness, including numeric abundance and aggregate weight or biomass. As will be illustrated shortly, all of these community parameters exhibited the same basic pattern over space (Gammon 1976). Therefore, it was decided to combine two indices of diversity and two suitably weighted indices of abundance into a single composite index of well-being or Iwb which would reflect both the diversity and abundance of the fish community:

$$Iwb = 0.5 \ln No/km + 0.5 \ln Kg/km + Div(no.) + Div(wt.)$$

When the individual electrofishing catches are converted to Iwb values and plotted over the length of river under study a scattering of points is generated, as illustrated in Figure 95. The data set presented here is from the summer of 1988

when drought conditions reduced river discharge. Equipment failure was minimal thatyear and the linear Iwb profiles were based on three optimal collections taken during June and July.

The scatter of points is considerable, but the spatial trend of separate collection runs is consistent. Indeed, the overall Iwb profile based on mean values is clear (Figure 96). The Iwb values are relatively high and steady in upriver areas. The shifts which do occur are for the most part gradual regardless of the direction of change, increasing or decreasing through space. Downriver from about RM 270 (Covington, Indiana) the Iwb values steadily decline and become much more erratic. Collections in adjacent stations sometimes differ widely.

In order to simplify interpretation further the entire study section was subdivided into smaller segments called Reaches. The delineation of each Reach was not completely arbitrary. Rather, it was based on a growing familiarity with the river and assessments that water quality was quite uniform throughout each Reach. Ultimately, each Reach was characterized annually by an average of electrofishing samples from 5 collecting stations, totalling 15 per Reach for most years. Figure 97 reduces the 1988 data to mean Iwb values for each Reach, thereby characterizing the diversity and abundance of the fish communities Reach by Reach throughout the middle Wabash River.

All individual components of the Iwb exhibit the same basic pattern of change over the 12 Reaches (Figure 98), as do species numbers. The average number of species taken per sample declined more steeply, but was of the same numerical magnitude and exhibited the same spatial pattern as the Iwb.

Relative numbers (No/km) and biomass (Kg/km) were somewhat more variable, but they also displayed the same fundamental pattern. The values for the two Shannon-Weiner diversity indices, while much lower and less variable, also followed suit. Diversity values based on biomass were always lower than diversity values based on numbers, even for most individual collections. Some other community attributes also appear to vary in similar fashion. For example, the mean number of species per collection and the total number of species collected per Reach varies, as shown in Figure 96.

All of the community values were somewhat depressed at the Cayuga electric generating station (Reach 6) and even more strongly depressed at the Wabash River electric generating station. The extent of this depression is somewhat exaggerated at both Reaches because all of the collecting stations are included, not just those which were comparable in habitat to other collecting sites.

The fish community in Reach 1 was the most stable in terms of constancy of calculated community parameters. For most years the community values from the individual collecting runs were similar. However, departures from this relative stability sometimes occurred. In 1983, for example, catches were uncharacteristically poor in June and early July and then improved slightly in late July (Figure 99). The cause of this depression has never been discovered. Bait seiners also reported very poor catches during the early summer of 1988 (Spacie, 1989).
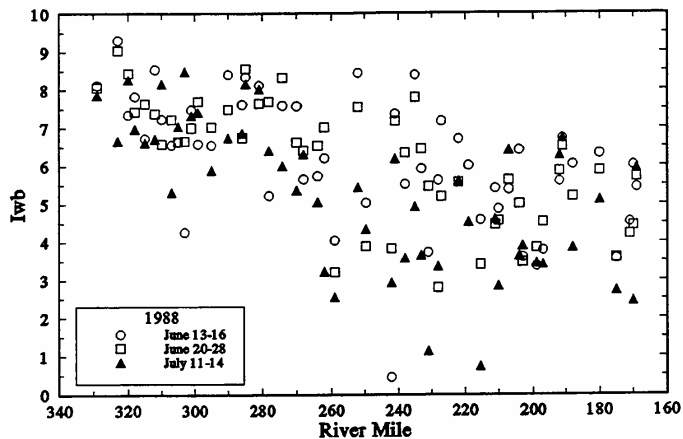
Figure 95: Iwb values for summer, 1988 based upon three electrofishing collections at each station. (All zones combined at Cayuga EGS (RM 249.6) and Wabash River EGS (RM 215.4).
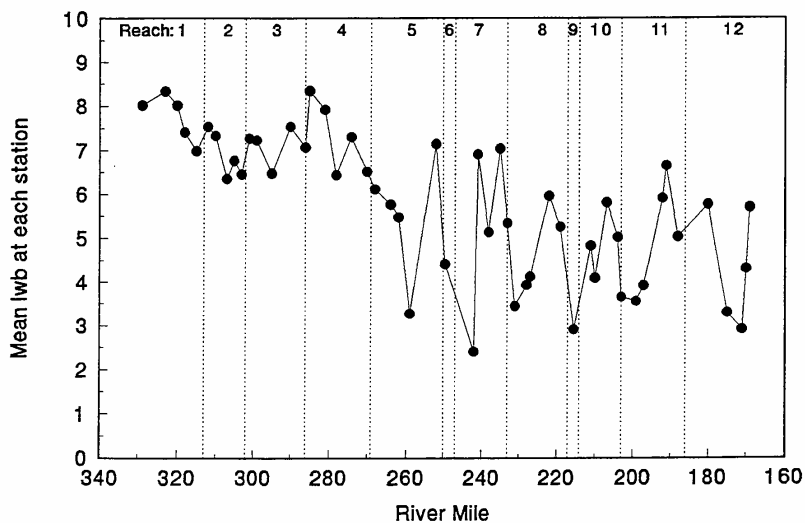
Figure 96: Mean Iwb values for 1988 at each collecting station. (All zones combined at Cayuga EGS (RM 249.6) and Wabash River EGS (RM 215.4).
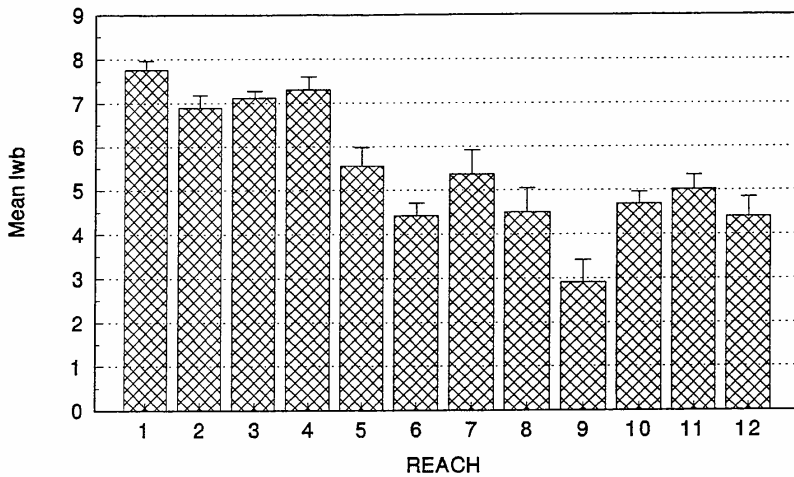
Figure 97: Mean Iwb values (+1S.E.) for each Reach in 1988.
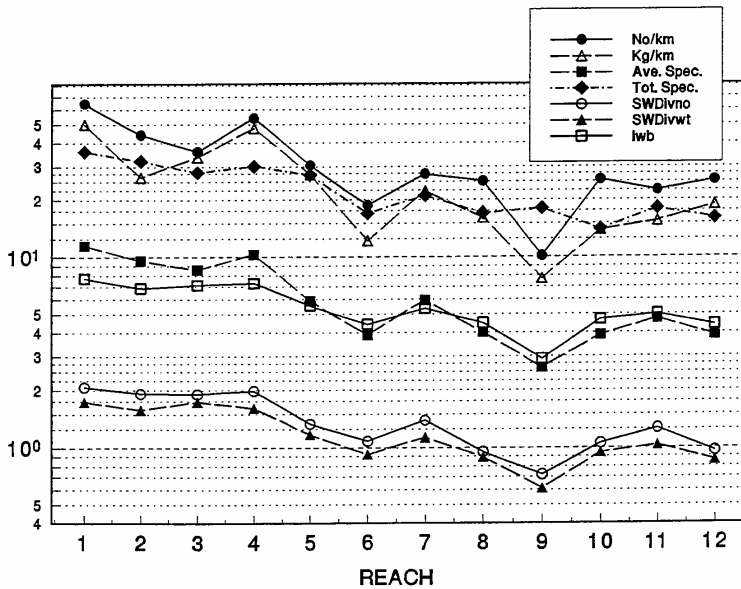
Figure 98: Spatial trends for community parameters derived from 1988 electrofishing catches.

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Figure 99: Iwb profiles of individual series of catches 1977, 1983, 1986, and 1988.
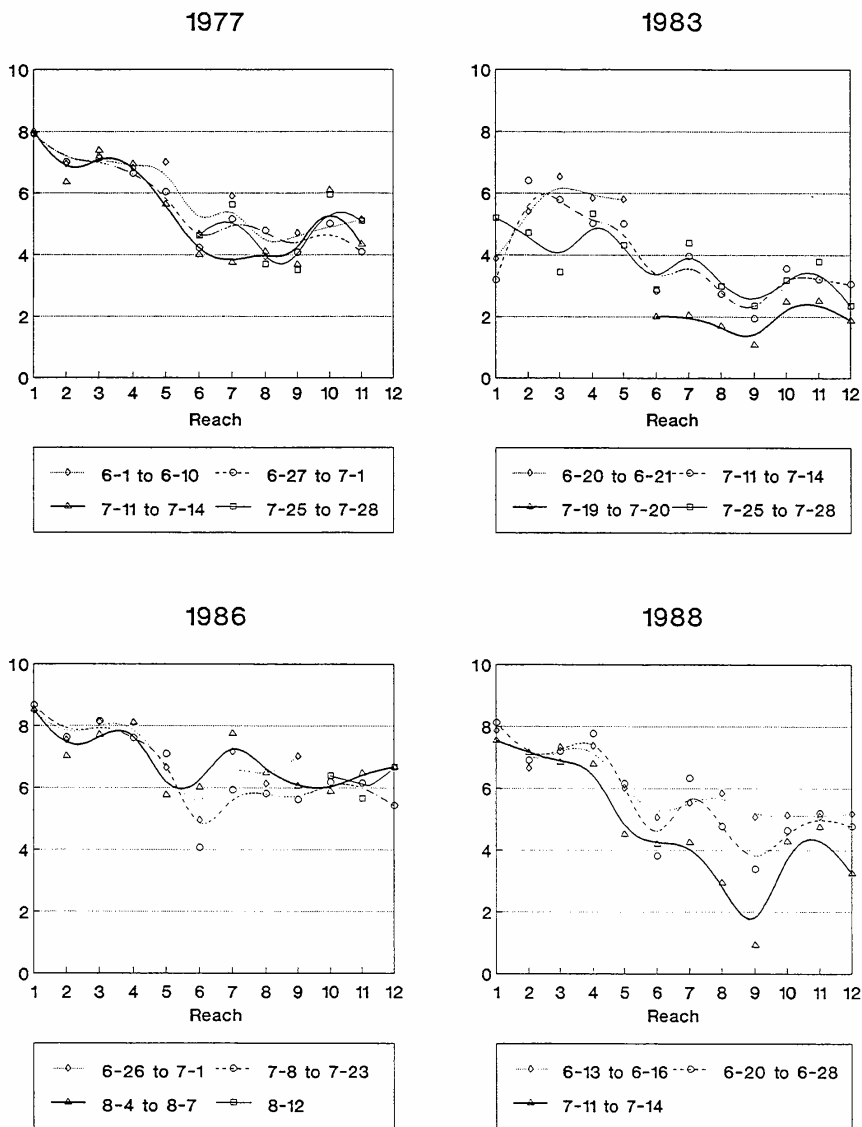
The community values from Reaches 6 and 7, on the other hand, sometimes fluctuated considerably from one electrofishing pass to another (Figure 99). A distinct decline in catches during early summer of 1977 preceeded a fish-kill in this section of river later on (Gammon and Reidy 1981). In 1988 an even more severe depression occurred in July which extended through Reaches 7, 8, 9, and 12, indicating that much of the lower Wabash River was environmentally stressed. A similar phenomenon may have occurred in 1991, but equipment problems made it necessary to engage in piecemeal collections and the pattern generated was not clear.

Figures 100 through 105 summarize the changes that occurred in community parameters over time and space. The pattern of change for the composite index of well-being (Iwb) (Figure 100) is generally reflected by all of the other community indices. Considered as a whole, the fish community of the middle Wabash River improved measurably from 1973 to 1993.

The year 1983 was especially critical. Before 1983 the fish community was unremarkable and it was altogether poor in 1983. However, the widespread reproductive success that year and the survival of young through the first year resulted in a much improved fish community a few years later. Most species populations expanded in size after 1983 and even changed in distribution abundance. This collective change, in turn, led to an increase in magnitude of the community parameters.

Low diversity and abundance characterized the fish community during the droughty summers of 1976-77, 1988, and 1991, as indicated by deep notches in the Iwb

shown in Figure 100. Not all Reaches were affected, however. The 1976-77 and 1988 droughts did not affect either electrofishing catches or the derived community parameters in the upper Reaches (Reaches 1-4), but clearly depressed them in all Reaches downriver from Covington (Reaches 5-12). The impact of the 1991 drought was apparently more severe and resulted in lowered catch rates and community parameters in all 12 Reaches. The summer of 1983 began with steady and moderate discharge rates which diminished to drought levels by late July and August.

The flood of 1993 was devastating to most species populations and strongly depressed the catches and derived community parameter values in 1993 and 1994. The Wabash River was high, if not flooded, for most of the summer. Not until August did the water levels even approach conditions which were desirable for successful electrofishing. Post-flood catch rates were reduced to less than 50% of the 1992 catch rate for the following species: gizzard shad, golden redhorse, shorthead redhorse, river redhorse, blue sucker, smallmouth buffalo, longnose gar, shortnose gar, goldeye, skipjack herring, white bass, smallmouth bass, and spotted bass. Almost all other species were also reduced to a lesser degree.

It is likely that reproduction was poor in 1993 because most species spawn during spring and early summer and the resulting fry would be exposed to unusually high, turbid water for an extended period of time. Such conditions would rapidly sweep planktonic fry downriver. It would also interfere with location of food.

Yearling gizzard shad were also devastated. Younger, immature members of

other species populations were apparently also affected negatively because only the larger individuals remained for many species, including golden redhorse, flathead catfish, channel catfish, and smallmouth bass.

Moderate discharge rates occurred during the summer of 1994. Perhaps the phenomenon of 1983 will reappear and another cycle of abundance will have been initiated.
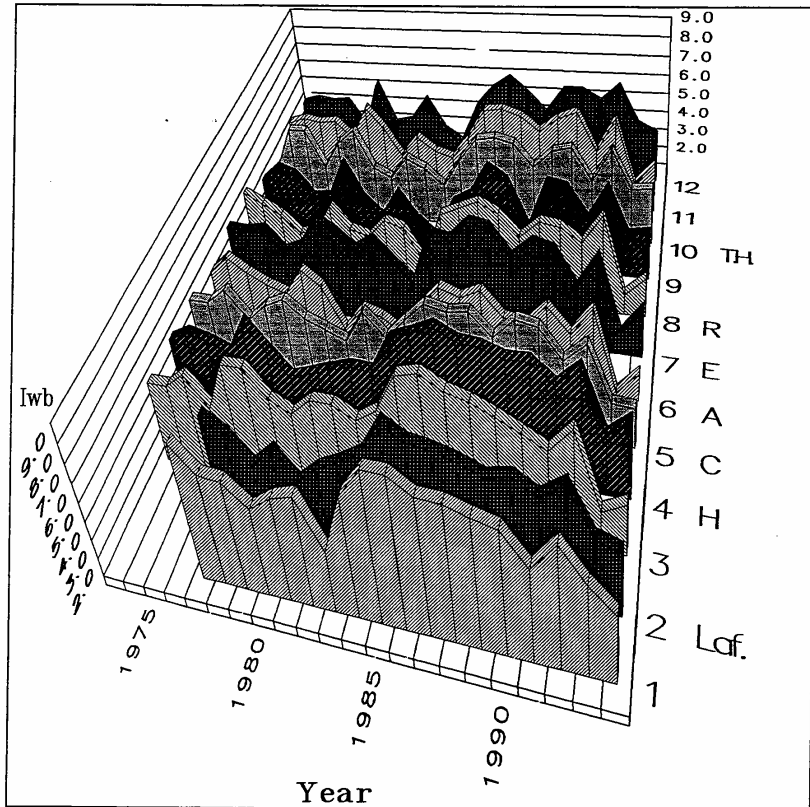
Figure 100: Mean Composite Index of Well-being (Iwb) values of 12 Reaches of the middle Wabash River 1973- 1994.
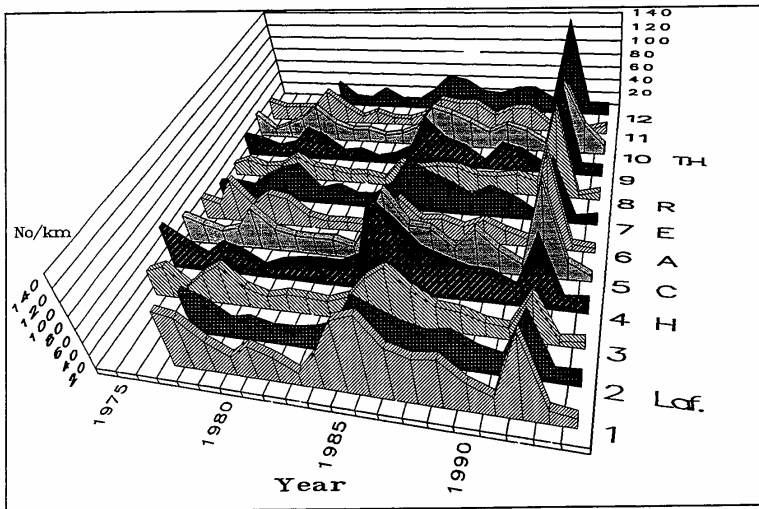
**Figure 101: Mean relative abundance values (No/km)
for 12 Reaches of the middle Wabash River 1973-1994.**
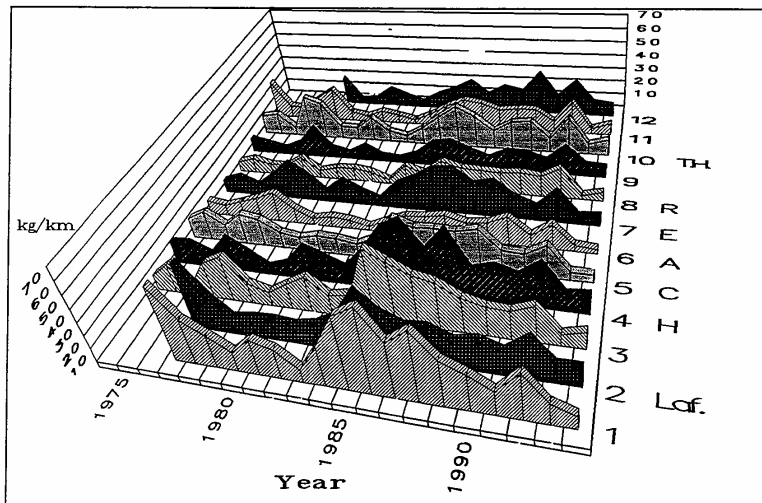
**Figure 102: Mean relative biomass values (Kg/km)
for 12 Reaches of the middle Wabash River 1973-1994.**

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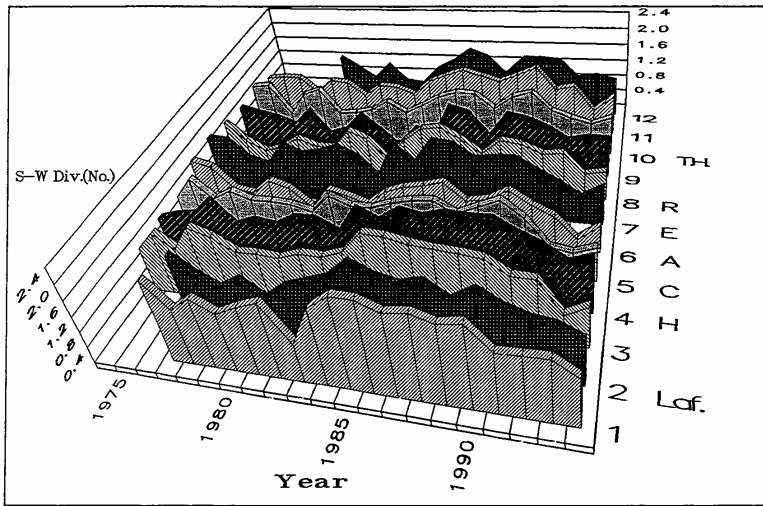
Figure 103: Mean Shannon-Weiner Diversity values based on numbers
for 12 Reaches of the middle Wabash River 1973-1994.
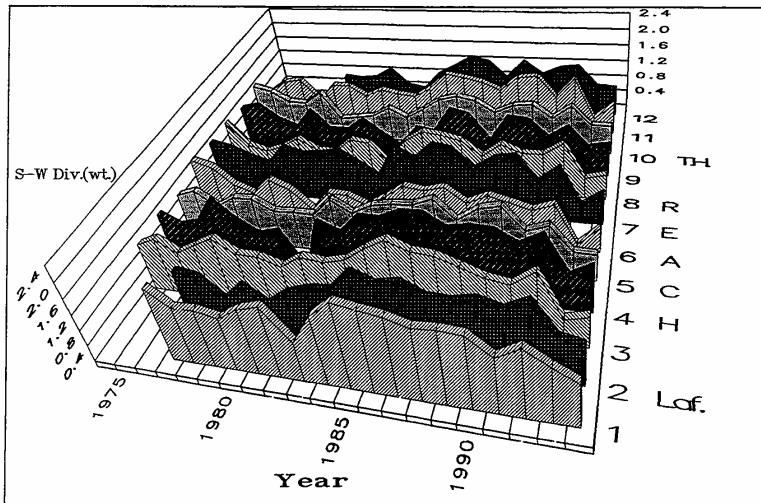
Figure 104: Mean Shannon-Weiner Diversity values based on biomass
for 12 Reaches of the middle Wabash River 1973-1994.
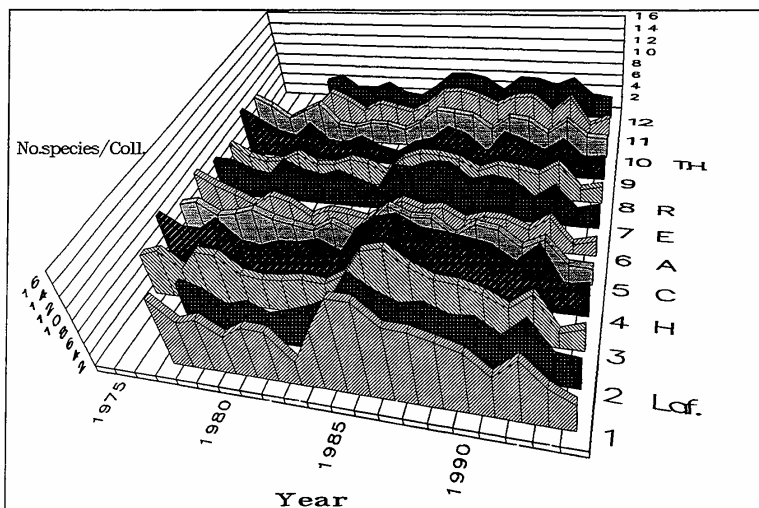
Figure 105: Mean number of species of fish per electrofishing collection
for 12 Reaches of the middle Wabash River 1973-1994.

Coefficients of variation (V) were calculated on all of the community indices for the years 1975 through 1990 in order to examine (1) the relative variability among the different community parameters and (2) community stability of the Reaches (Table 9).

Catch density (No/km) and catch biomass (Kg/km) were the most variable of all parameters (V range = 62 to 112). Iwb values and evenness values were the least variable community parameters (V range = 19 to 55). The variability of evenness by numbers and eveness by weights were similar. The two Shannon-Weiner diversity indices were equally variable and ranged between 27

and 65. The average number of species per collection varied considerably (V range = 42 to 55).

The community parameters were most stable in Reach 1 and least stable in Reaches 6 and 9 (Cayuga EGS and Wabash River EGS). Reaches 2 and 10 (Lafayette and Terre Haute, Indiana) also were slightly more variable than immediately flanking Reaches. There was, in general, a gradual increase in variability downriver. This analysis reinforces the assumption that Reach 1 was the best "reference" or ambient Reach and that the Iwb was the best community parameter to use for statistical analyses and evaluation.

Table 9: Coefficients of variation (V) for community parameters using 1975 to 1990 data.

Reach	No. per Km	Kg per Km	Ave. No. Spec	Div. No.	Div. Wt.	Even No.	Even Wt.	Iwb	Mod. Iwb
1	62.6	62.5	42.1	29.4	27.5	19.6	19.4	22.4	23.8
2	63.8	77.7	47.8	34.6	37.8	19.4	25.2	27.3	37.7
3	73.6	73.2	45.6	37.5	33.6	19.1	21.6	26.7	29.5
4	88.2	85.6	43.2	32.6	32.0	23.2	23.1	26.1	27.6
5	91.2	72.6	42.7	40.1	38.4	31.8	28.4	26.5	29.6
6	112	94.8	54.8	65.3	58.4	54.9	48.2	38.0	39.9
7	77.3	81.1	48.5	44.8	41.8	32.4	30.1	28.5	29.9
8	68.5	77.2	50.6	48.3	49.8	32.8	34.3	35.1	37.6
9	107	95.5	57.0	60.1	58.8	49.6	48.2	45.9	49.0
10	80.5	107	51.4	48.0	49.7	33.9	38.6	35.8	39.4
11	73.0	79.9	53.8	45.6	50.6	31.7	37.6	37.1	41.5
12	72.1	104	52.7	47.0	52.0	33.0	39.3	35.2	41.5

Before 1984 the annual electrofishing catches produced relatively few so-called sport fish or game fish, ie species of fish sought by recreational anglers either for their sporting abilities or their edibility. Prior to 1973 all of the collecting effort was concentrated at two restricted locations, the Wabash River electric generating station and the future Cayuga electric generating station which was then under construction. The electrofishing catch rates averaged only one to two game fish per kilometer at that time (Figure 106).

Beginning in 1973 the studies were broadened to include sections of river north of the Cayuga EGS as well as the section of river between Cayuga EGS and Wabash River EGS. The average catch rate then increased to three to four game fish per kilometer. During the entire period the average value of the index of well-being was usually less that 5.0 units.

It was the appearance of greatly enlarged catches of game fishes, especially smallmouth bass, in 1984 that first alerted us to the changes which were to occur. The game fish catch rate that year exceeded nine per kilometer including much higher than usual numbers of flathead catfish, white bass, and smallmouth bass. This population boom was sustained for several years and declined substantially on in 1990. If freshwater drum were to be included in the game fish category the magnitude of the increase would be far greater than is shown in Figure 106.

It appeared that another population expansion was underway by 1992, but the 1993 flood brought an end to that possibility.

The expansion of both game fish and nongame fish populations during this period was caused by enhanced reproductive success throughout the basin and survival in the Wabash River mainstem. The comparison of pre-1983 and post-1983 catch rates for some important taxa shown in Figure 107 indicate the positive increases for most species populations except for gizzard shad and carp. A successful yearclass of fry produced a healthy crop of yearlings which were sampled by electrofishing the following year. Such an expansion of young fish in the population should have had the effect of reducing the average size, but this did not occur for several species and the reduction in size for many species was insignificant.

The enormous population increase of channel catfish did result in a 25% reduction in the mean size of fish following 1983 (Figure 108). Smaller reductions also occurred in populations of mooneye, white bass, and sauger. However, for many other expanding species populations there was actually an increase in mean weight. The various species populations of redhorse experienced increases in the mean weight as did sturgeon, gar, flathead catfish, drum, goldeye, and spotted bass.

This unexpected phenomenon suggests that members of these species populations are living longer and/or growing faster. If, indeed, these aspects of population biology have changed it is probably yet another indication of more favorable environmental conditions. These aspects need to be examined in greater detail.

No/km   Iwb
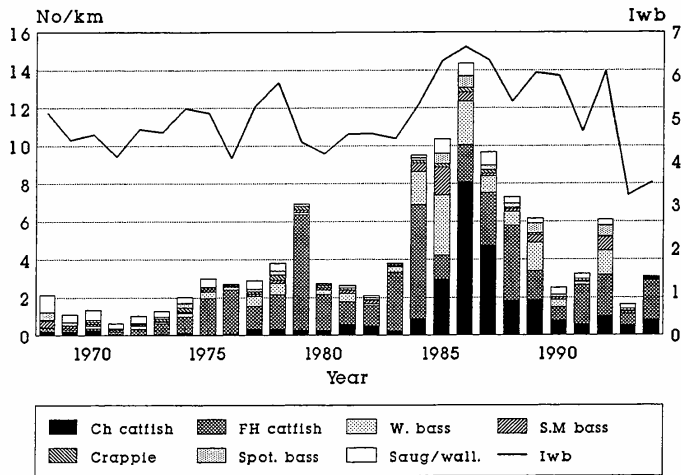
Figure 106: Annual electrofishing catch rates (No/km) of some sport-fishes
of the Wabash River 1968 - 1994.
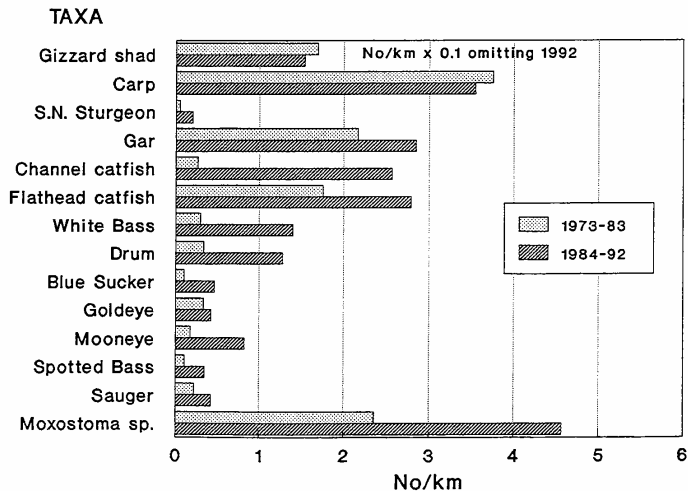
TAXA

Figure 107: Comparisons of electrofishing catch rates (No/km)
of some taxa of Wabash River fishes, 1973-1983 vs 1984-1992.
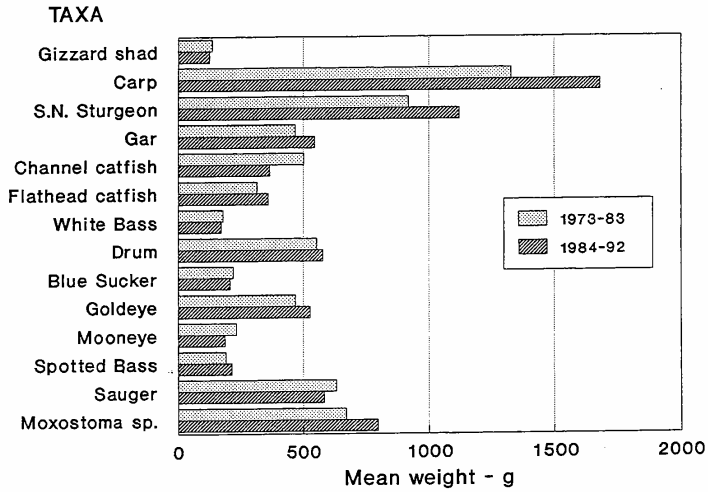
Figure 108: Comparisons of the mean weight (g)
of some taxa of Wabash River fishes 1973-1983 vs 1984-1992.

Community Parameters
and Quality of Fish Communities

No midwestern rivers are undisturbed by human activities, especially rivers the size of the Wabash. If such a river existed, it would support a biotic community which could serve as a standard by which all of the impacted rivers could be compared. That conclusion was reached after a prolonged and futile search to locate some such a standard, even in the literature.

Since no unpolluted river was found to exist, it was imperative to locate a reference segment of the Wabash River which was least disturbed. For the middle Wabash River the least disturbed segment is Reach 1 which is located between Delphi, Indiana and Lafayette, Indiana. Reach 1 usually supported the "best" fish community of all of the Reaches. Even here, however, the fish community was clearly impacted negatively during early summer in 1983.

There is a distinct advantage in having studied the Wabash River over a long period of time during this period of history. The past 25 years embraces an era during which society has, for perhaps the first time, focused its attention on improving environmental quality in lakes and rivers. Furthermore, significant monetary and technological resources were devoted to the daunting task of reducing pollution and its effects. Underlying this enormous effort was the assumption that most of our surface waters were being negatively affected by the by-products of man's diverse activities. It was further assumed that if pollutional loadings to our lakes and rivers were reduced then the biotic communities inhabiting those waters would benefit and improve in quality.

Some sections of the middle Wabash River have clearly suffered from pollutional effects for a long period of time. On the other hand, recent changes in the fish communities have been spectacularly positive. The range of quality in the fish communities of specific Reaches over the period of study makes it possible to extend the numeric Iwb evaluations to statements about community quality. Table 10 summarizes attributes of "excellent", "good", "fair", and "poor" fish communities in terms of community parameters and other qualities.

The line of delineation (Iwb equal to or greater than 8.5) for an "excellent" community was determined by the very best fish community observed during the period of study, the community of Reach 1 during 1985-86 (mean Iwb = 8.6). The line of delineation for a "poor" community (Iwb less than or equal to 5.5) was exemplified by the fish community in Reach 8 during 1973-75 (mean Iwb = 4.85), although several other Reaches or locations would have been equally suitable. The intervening distance between these designations was bisected at Iwb = 7.0 to provide ranges for "fair" fish communities (Iwb value is between 5.5 and 7.0) and "good" fish communities (Iwb value is between 7.0 and 8.5).

The ranges of Iwb values indicated for each quality grouping reflect differences in most other measures of community, sport fish abundance, and trophic composition. Only **Evenness** indices and **percent biomass as piscivores** failed to vary over the range of fish communities found in the middle Wabash River from 1968 through 1993. Some other compositional attributes of the four quality groupings are summarized in Figure 109 in which pie size is proportional to abundance.

Table 10: Community parameters and qualitative evaluations of fish communities in the Wabash River.

PARAMETER	EXCELLENT	GOOD	FAIR	POOR
Community				
Iwb	> 8.5	7.0-8.5	5.5-7.0	< 5.5
Av. No. Species	> 15	8 - 15	5 - 8	< 5
No/km	> 100	60 - 100	25 - 60	< 25
Kg/km	> 50	25 - 50	15 - 25	< 15
Div. (no.)[*]	> 2.2	1.7 - 2.2	1.3 - 1.7	< 1.3
Div. (wt.)[**]	> 2.0	1.5 - 2.0	1.1 - 1.5	< 1.1
Even (no.)	0.75 - 0.90	0.75 - 0.90	0.75 - 0.90	0.75 - 0.90
Even (wt.)	0.7 - 0.8	0.7 - 0.8	0.7 - 0.8	0.7 - 0.8
Sport Fish[***]				
(No/km)	> 20	12 - 20	4 - 12	< 4
Trophic Composition				
% wt. Piscivores	15 - 30	15 - 30	15 - 30	15 - 30
% wt. Insectivores	> 30	15 - 30	5 - 15	< 5
% wt. Herbivores	< 10	10 - 20	10 - 20	> 20
% wt. Detritivores	> 5	2 - 5	1 - 5	< 1
% wt. Omnivores[****]	< 40	< 40	40 - 60	> 60

[*] Shannon diversity based on numbers
[**] Shannon diversity based on weight
[***] Centrarchid bass, white bass, catfish, sauger, walleye, sunfish, and crappie
[****] Carp exclusively in this study

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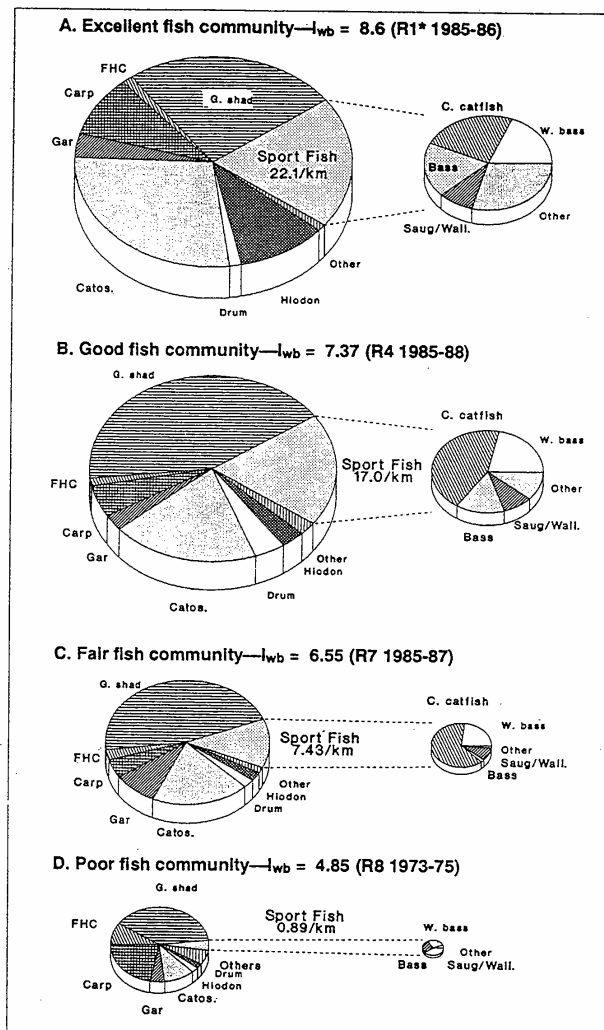
Figure 109: Examples of excellent, good, fair, and poor fish communities in the middle Wabash River.

Comparison of Fish Communities
before and after 1983

The improvement in the fish community that occurred throughout the Wabash River from 1973-83 to 1984-92 was remarkable. The increases in values for most community parameters were statistically significant (Table 11). Numeric and biomass catch rates increased markedly, Shannon-Weiner diversities and Iwb values increased substantially, and evenness values rose slightly. The changes in other community parameters were even greater. The Iwb values and both Shannon-Weiner indices of diversity increased, as did the mean number of species captured per collection.

The elevation in community parameters was caused by the expansion of most species populations, except for carp and gizzard shad. For example, from 1974 through 1983 the combined catch rate of sport fishes averaged slightly more than 2.0/km and then more than quadrupled during 1984-87 (Figure 106). Many other species populations also increased, especially in the upper river (Figure 107).

Most species of fish that reproduced and lived in the mainstem increased greatly in density throughout the river (e.g., channel catfish, flathead catfish, sauger, spotted bass, northern river carpsucker, blue sucker, and drum). Some species populations expanded their ranges into previously unoccupied areas of the river. Blue sucker catches tripled as fish moved into both the upper river (Reaches 1-4) and the lower section down-river from Terre Haute, Indiana (Reaches 9-12). Mooneye, sauger, smallmouth bass, and spotted bass became important components catches in Reaches 1 through 4. Goldeye

and shortnose gar increased mainly in the lower Reaches.

Population increases also occurred for white bass and walleye coming from offriver reservoirs and from clean tributaries (smallmouth bass and longear sunfish). During this period carp abundance was quite constant and gizzard shad populations declined notably. The latter was probably related to increased predator pressure from a greatly expanded piscivore populations.

The most remarkable phenomenon was how quickly the entire community changed. The 1983 catches were dismal (Figure 110). Three years later the 1986 catches were outstanding and produced the highest Iwb values ever observed. The quality of the community after 1986 gradually diminished, but rebounded again in 1992.

The improvement extended into thermally influenced parts of the river at Cayuga Electric Generating Station (Reach 6) and the Wabash River Electric Generating Station (Reach 9). Changes here will be examined more closely in a later section.

The 1993 flood depressed Iwb values in all Reaches proportionately. Iwb values in the lower Reaches were only marginally smaller than those in the upper Reaches. In other words, the flood influenced the entire river negatively. In contrast, the impact of droughts in 1983 and 1988 was much greater in the lower Reaches, where water quality was lower, than in the upper Reaches.

Table 11: Statistical changes in the values of fish community
parameters (mean & S.E.) from 1973-83 to 1984-92.

COMMUNITY INDEX	1973-83	1984-92	T	% Change
No/km	29.93 (0.77)	51.09 (1.42)	1.83	+70.7
Kg/km	13.43 (0.34)	22.18 (0.46)	3.81**	+65.2
No. Species/collection	4.93 (0.07)	6.88 (0.09)	3.11**	+39.6
S-W Diversity(no)	1.097 (0.014)	1.399 (0.015)	3.33**	+27.5
S-W Diversity(wt)	1.002 (0.013)	1.314 (0.013)	3.90**	+31.1
Evenness(no)	0.71 (0.007)	0.76 (0.057)	1.41	+7.0
Evenness(wt)	0.65 (0.006)	0.71 (0.004)	3.79**	+9.2
Index of Well-being	4.64 (0.043)	5.86 (0.041)	4.01***	+26.1

* $P < 0.05$ ** $P < 0.01$ *** $P < 0.001$
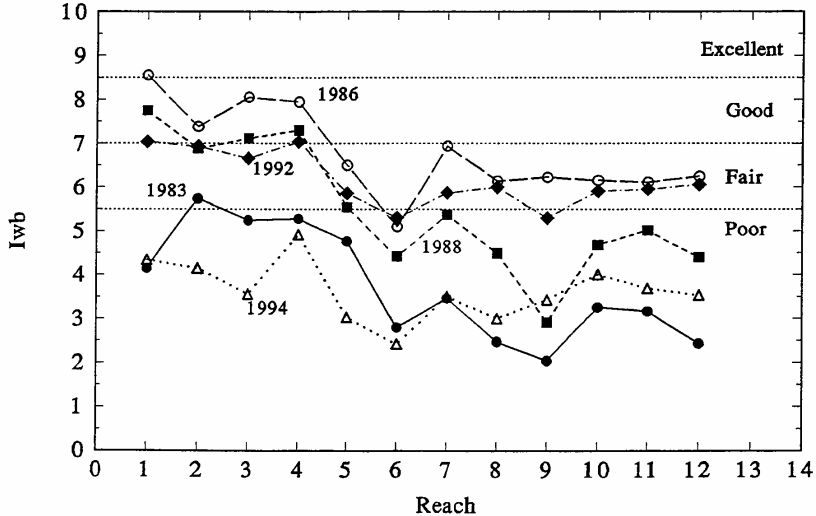
Figure 110: Longitudinal profiles of mean Iwb values in
1983, 1986, 1988, 1992, and 1994.

The recent improvements in the fish community probably resulted from a combination of events, including a long-term 50% reduction in BOD loading, the result of improvements in industrial and municipal waste treatment during the 1970's and early 1980's. The summer of 1983 was a low-flow summer, which has been shown statistically to facilitate good reproduction and survival through the first year for most mainstem species of fish. That particular year also produced the Payment in Kind (PIK) program, when farmers were paid not to grow crops. In Indiana this led potentially to a 25% reduction in agricultural loadings to the river because 25% fewer acres of corn and soybeans were tilled and, presumably, 25% less fertilizer and herbicides were applied.

The average catch rates of 33 species of fish from the entire study section of the Wabash River were analyzed by a detrended correspondence analysis (DCA) comparing the periods 1973-83, 1984-92, and 1994 (Figure 111). Gizzard shad was excluded from the analysis because of its large dominance and variability of catch rates.

Figure 111A emphasizes upper Reaches 1-5 and lower Reaches 10-12 and shows the relative community changes which occurred after 1983 and the effect of the 1993 flood. The best communities in Reaches 1-4 became more similar to each other after 1983. Reach 5 contained fish communities intermediate between the upper Reaches and lower Reaches prior to 1983. However, after 1983 the Reach 5 community was quite similar to those in the upper

Reaches. The communities of Reaches 1-5 remained similar to each other after the 1993 flood, but was strongly altered as shown by the downward shift in location.

The community changes in the lower Reaches (10-12) after 1983 were positive as indicated by the rightward shift to a position closer to the upper communities. The effect of the flood was not as severe for these communities as for those in the upper Reaches. However, there were substantial differences among the lower Reach communities with Reach 11 having the best community.

Figure 11B shows changes for these same time periods for the intermediate Reaches. Reaches 6 (Cayuga EGS) and 9 (Wabash River EGS) communities also improved after 1983, ie. shifted toward the upriver group. The positions for Reach 7 indicate communities somewhat recovered from the thermal changes created by the Cayuga EGS, but a relatively large impact by the 1993 flood.

Reach 8 was the only Reach to have communities reduced in quality after 1983. The 1993 flood added its negative impact not only to the community in Reach 8, but also to that of the Reach 12 community. Again, the fish communities and environmental problems of this particular Reach should be investigated much more thoroughly. Unknown factors have been and continue at the present time to negatively influence Reach 8 and, perhaps, the other Reaches downriver.
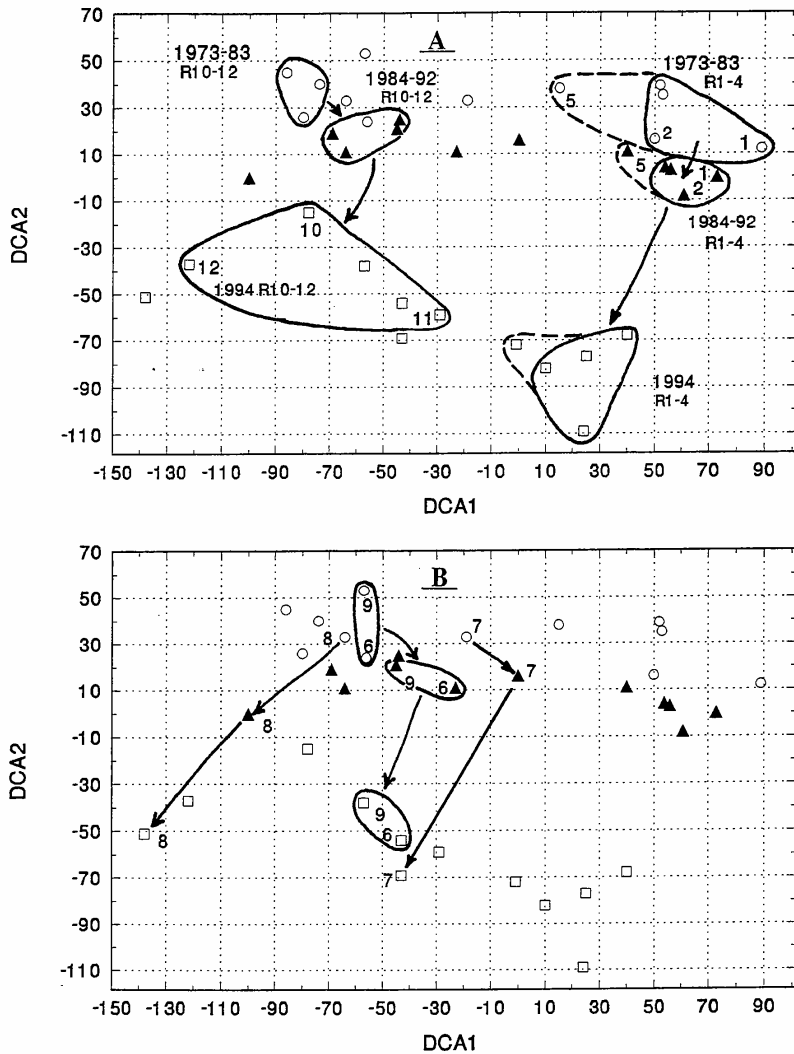
Figure 111: Detrended correspondence analysis of catch data (No/km) for each
Wabash River Reach for the periods (a) 1973-83, (b) 1984-92, and (c) 1994.
A: Emphasis on changes in the upper five Reaches (1-5) and the lower three Reaches (19-12).
B: Emphasis on changes at the electric generating stations (6 and 9) and Reaches 7 and 8.

Another way of gauging the degree to which fish communities of the individual Reaches have changed is to first calculate a ratio consisting of the composite index of well-being (Iwb) for each individual Reach divided by the Iwb value of Reach 1 and then compute a linear regression of this ratio over time. This regression examines the temporal change of the Iwb of each Reach relative to the Iwb values of Reach 1. One advantage of this technique is that it tends to neutralize the variable effects of annual differences in weather, river flows, and collecting efficiency of the electrofishing crews.

Data from the years 1976, 1983, and 1993 was excluded from the regression analysis. The 1976 data was not included because no collections were made in Reach 1 that year. Data from the year 1983 was exempted because of the forementioned anomalous and unexplained depression in Iwb values in Reach 1. As discussed previously, the available 1993 data was limited because of high water and poor collecting conditions. Therefore, it has also been excluded.

The results of this analysis are summarized in Table 12 and Figure 112. Despite considerable scatter of data all Reaches yielded positive slopes, indicating generally improving fish communities relative to the community of Reach 1. Reaches 4, 8, 9, 11, and 12 changed most over time with statistically positive slopes ($P < 0.05$). The

Table 12: Regression of the ratio $IwbR_x \backslash IwbR1$ on time from 1975 through 1994.

Iwb Ratio	Regression Equation	R^2	p
R2\R1	Ratio = -14.05 + 0.00754 Year	0.21	0.07
R3\R1	Ratio = -4.215 + 0.00258 Year	0.06	0.35
R4\R1	Ratio = -30.05 + 0.01561 Year	0.71	0.000[***]
R5\R1	Ratio = -1.425 + 0.00113 Year	0.01	0.74
R6\R1	Ratio = -8.752 + 0.00473 Year	0.07	0.30
R7\R1	Ratio = -0.647 + 0.00076 Year	0.00	0.86
R8\R1	Ratio = -18.41 + 0.00962 Year	0.36	0.01[**]
R9\R1	Ratio = -21.73 + 0.01127 Year	0.23	0.05[*]
R10\R1	Ratio = -14.47 + 0.00766 Year	0.19	0.08
R11\R1	Ratio = - 24.46 + 0.01270 Year	0.42	0.01[*]
R12\R1	Ratio = -26.53 + 0.01370 Year	0.28	0.04[*]

[*] $P < 0.05$ [**] $P < 0.01$ [***] $P < 0.001$
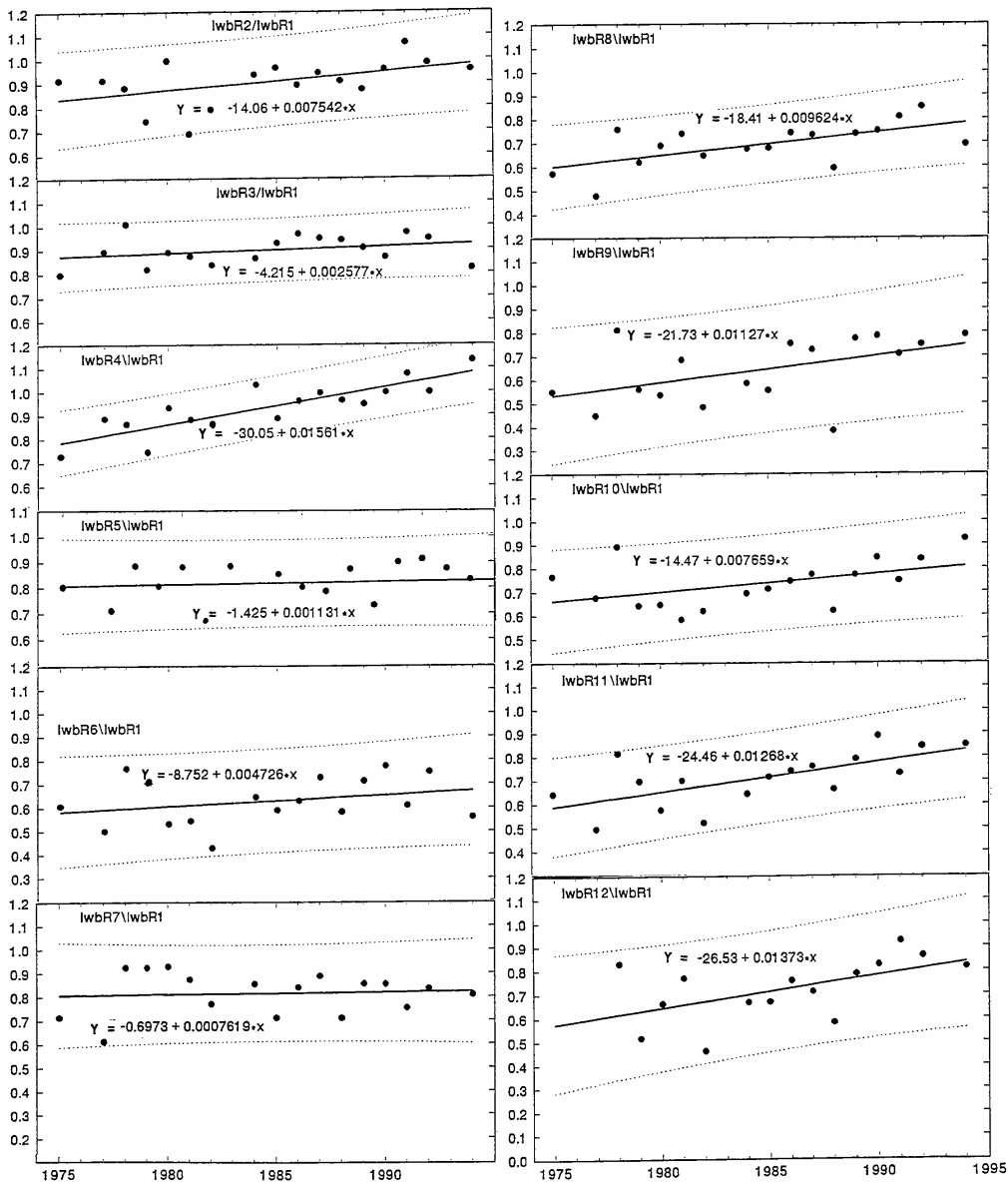
Figure 112: Change in the ratio IwbR$_x$\IwbR1 over time for Reaches 2 through 12. The regression equation and line and the 95% confidence interval are indicated.

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degree of improvement was almost as great for Reaches 2 and 10 (P<0.10). All of the other Reaches improved to a lesser extent, except for Reaches 5 and 7 where there was essential no change in the ratio over time.

The effects of low-flow summers of 1977 and 1988 on the Iwb ratios of Reaches 7, 8, 9, and 12 is accentuated in Figure 112 as points which deviate in a strongly negative direction from the trend line. The 1993

flood affected most Reaches to the same extent, with only pronounced negative deviations from the trend line only in Reaches 2, 5, and 8.

The year 1978 marked a time when the Iwb ratios for most Reaches was considerably higher than the trend line for unknown reasons. Overall, the regression analysis corroborates the changes indicated by the DCA and other analyses.
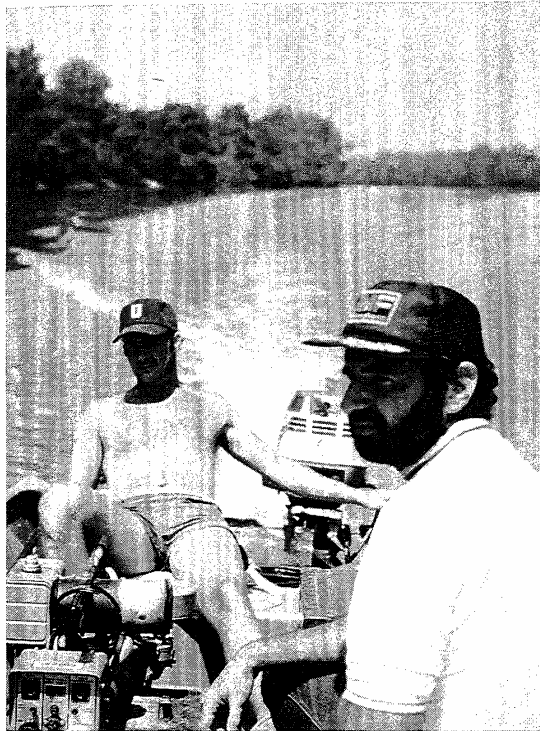
Joe Reidy motors to the next collecting sites
while Pete Redmond watches out for unforseen obstacles.

The Commercial Fishery of
the Wabash River

In Indiana, the commercial fishery using nets is limited to about 900 km (560 miles) of the Wabash, White, and Patoka rivers and 580 km of the Ohio River (Stevanavage 1990; Blackwell 1991). The lower 325 km (200 miles) of the Wabash River forms the boundary between Indiana and Illinois and may be fished without limits of the numbers of nets or seines. Indiana waters, however, may be fished by a maximum of four hoop or trap nets with stretched mesh not less than 5 cm. The license is free, but each required metal net tag costs $4.

Most of the commercial harvest is used directly by the fishermen and their families. Few fishermen, if any, derive their entire income from the river, although some fish may be sold locally.

The number of commercial licenses issued annually from 1974 to 1990 fluctuated between 800 and 400. In 1977 a policy was adopted which mandated reporting the commercial harvest. This led to a 40% decline in licensed fishermen in 1978.

In January 1985 a fish consumption advisory was issued for the Wabash River from Lafayette, Indiana to Darwin, Illinois and for the West Fork of the White River from Broad Ripple in northern Indianapolis, Indiana to its junction with the East Fork of the White River near Petersburg, Indiana. This may have been the reason for a 20% decline in commercial fishing licenses from 605 in 1984 to 447 in 1986 (Glander 1987). It may also explain the 20% decline in overall harvest. During this period, however, there was an increase in catches of the most important species in the commercial catch (channel catfish and flathead catfish). The decrease was mainly because of reduced catches of carp, suckers, and drum. Catfish species currently constitute about 70% of the harvest.
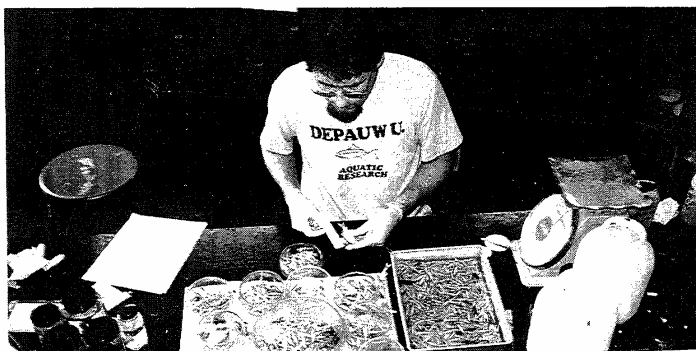
Cliff Gammon identifies and measures a sample of small fish in the laboratory.

Mollusca of the Wabash River

Most studies of Wabash River mollusca have focused on commercially valuable species of clams. No comprehensive studies of snails have been conducted. The shells of many species of clams were used in making buttons from the late 1890's through mid 1900's, when plastic replaced shell. More recently, the cultured pearl industry mills sections of shells into round "seeds," which are then implanted into pearl oysters to create cultured pearls.

Most recently Cummings et al. (1987, 1988, 1991) examined the abundance and distribution of clams of the Wabash, White, and Tippecanoe rivers. They found a drastic reduction in range and abundance of many species formerly common and widespread on the upper and middle Wabash River. The three most abundant species were *Obovaria olivaria, Leptodea fragilis*, and *Quadrula quadrula*, which made up 61% of the live mussels collected (Figure 113).

Fourteen of 26 mussel collection sites were located within our 12 Reaches. Other sites were located up- and down-river. The hickorynut (*Obovaria olivaria*) was common throughout the middle Wabash River except between the mouth of Big Vermilion River and Terre Haute. It constituted 30% of the live clams collected and appeared to be as common in recent years as it was in the past. Nevertheless, this species is growing scarce in other rivers including the Mississippi and upper Ohio (Cummings and Mayer 1992)

Fragile papershell (*Leptodea fragilis*) accounted for 22% of all live mussels collected by Cummings et al. (1988). Its distribution was virtually identical to that of the hickorynut.
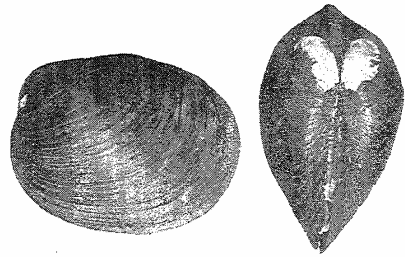
Obovaria olivaria
(Hickorynut)
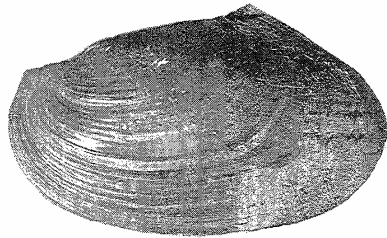
Leptodea fragilis
(Fragile Papershell)

Quadrula quadrula
(Mapleleaf)

Figure 113: The most common species of clams in the Wabash River.
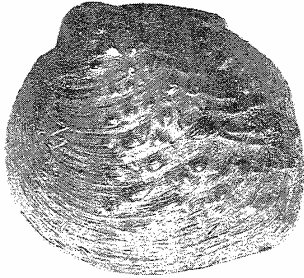
Quadrula pustulosa
(Pimpleback)
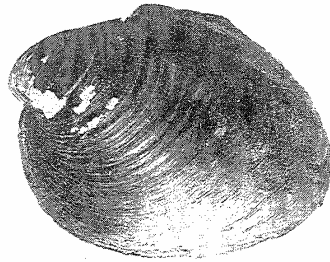
Fusconaia ebena
(Ebonyshell)
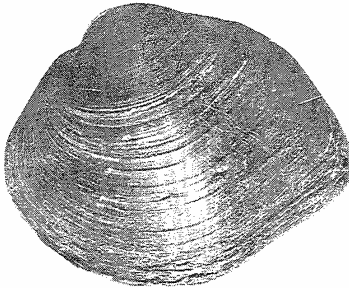
Fusconaia flava
(Wabash Pigtoe)
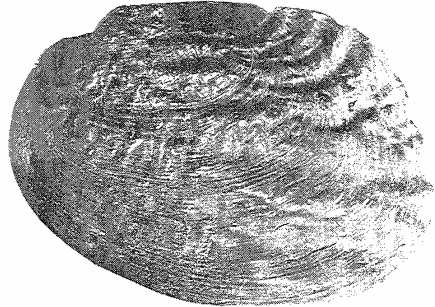
Megalonaias nervosus
(Washboard)
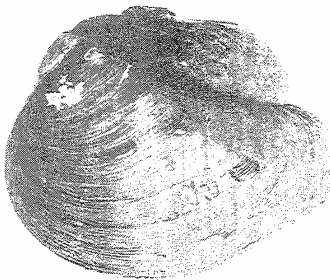
Quadrula metavevra
(Monkeyface)
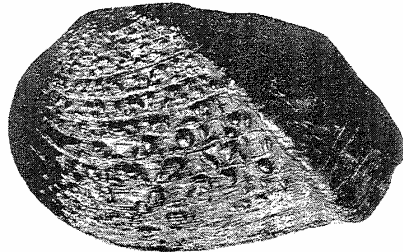
Tritogonia verrucosa
(Pistolgrip)

Figure 114: Some other commercially valuable mussels of the Wabash River.

The mapleleaf (*Quadrula quadrula*) accounted for 9% of live mussels in the 1988 study and was common except at sites between Big Vermilion River and Terre Haute, Indiana where it was rare.

Three species of mussels considered to be endangered or threatened (Williams et al. 1993) were also found in 1988: (1) fanshell (*Cyprogenia stegaria*), (2) rabbitsfoot (*Quadrula cylindrica*), and (3) sheepnose (*Plethobasus cyphyus*). A single live fanshell was found below Hutsonville. One live rabbitsfoot was found downriver from Lafayette. Six live sheepnose were found near Delphi. Only the shells of 14 other rare, endangered, or extinct species were found.

The Wabash River was once occupied by over 75 species of unionids (Call 1900; Blatchley and Daniels 1903; Daniels 1903, 1914; Goodrich and van der Schalie 1944). During 1966 and 1967, 30 species of Unionidae were collected at 63 sites from the lower sections of the Wabash River and East Fork White River (Krumholz et al. 1970).

The 10 species most important commercial market made up 77.1% of the total catch (*Quadrula quadrula, Obovaria olivaria, Q. pustulosa, Actinonaias ligamentina, Amblema plicata, Fusconaia ebena, Fusconaia flava, Megalonaias nervosa, Q. metanevra*, and *Tritogonia verrucosa*) (Figure 114). Overharvesting was considered to be the main cause for depleted commercial species. However, the negative effects of past increases in pollution on the overall fauna, including extirpated species of mussels which are not commercially valuable, has probably been significant (Anderson, personal communication).

Bingham (1968) found that the reproductive seasons of eight resident mussels differed greatly. The pistolgrip (*Tritongonia verrucosa*) was thought to reproduce during winter. The hickorynut (*Obovaria olivaria*) and mucket (*Actinonaias ligamentina*) are long-term breeders with the females becoming gravid in late summer and fall and shedding their glochidia early the following summer. In most other species, including all Ambleminae, the females became gravid in late spring or early summer and shed glochidia in late summer or fall.

Restrictions on commercial collecting methods were first instituted in April 1967 by prohibiting the use of mechanical dredges and diving with auxiliary air supplies. Acceptable, but less efficient methods of collection include handpicking, short forks, tongs, and crowfoot bar (brail) (Figures 115 and 116). The mussel season traditionally extends from April 15 through October 31, but most mussels are taken in June, July, and August. A minimum size limit of 64 mm protects smaller mussels. A $15 fee is charged for a license. Mussel harvest reports were collected by Indiana Department of Natural Resources (IDNR), but were not summarized or tabulated prior to 1988 (Henschen 1989, Stevanage 1992).

Sales of Indiana shells totaled 2,000 tons in 1965, 4,200 tons in 1966, 1,080 tons in 1967, and less than 250 tons in 1968. In 1991, 690 tons valued at $1.6-3.0 million were bought by mussel buyers. The East Fork of the White River and the Wabash River accounted for 76% of the total 1991 harvest.

A combination of extremely low river flows, which increased clam vulnerability during 1988 and 1991, and recent, high prices for clam shells led to a serious overharvest of

clams (Flatt et al. 1992). A total of 950 mussel harvesters purchased licenses in 1991, nearly quadruple the average sold from 1982 to 1990. Clammers combed exposed areas in the Wabash and White rivers and then extended their harvest efforts into tributaries.

On 11 September, 1991 clam harvest on exclusively Indiana waters was officially banned for an indefinite period, a move favored by most legal musselers. Plans for monitoring future population changes are currently underway. The commercial value of Wabash River mussels is sufficient reason in itself to examine this valuable resource in far greater detail than was done in the past. Past harvesting regulations have obviously been inadequate, however the extent to which point-source and nonpoint-source pollution affect mussel populations is not so apparent.

Aldridge et al. (1987) exposed three species of unionid mussels to 600 to 750 ppm diatomaceous earth and measured reduced rates of oxygen consumption, food clearance, and ammonia nitrogen excretion. However, Spacey and Chaney (1993) found no detectable changes in those physiological parameters when two species of unionid mussels were exposed to 500 and 1000 mg/l bentonite clay.

Cummings et al. (1988) found the Asian clam (*Corbicula fluminea*) at all Wabash River collecting sites from Wabash, Indiana down to the White River. However, it was not as abundant in the Wabash River as it is in the Ohio River and other southeastern United States rivers.

Zebra mussels (*Dreissena polymorpha*) have become established in the Ohio River, but they have not yet reached the middle Wabash River. However, there is little doubt that they will do so soon and resident mussels may well be influenced by yet another potentially damaging factor.
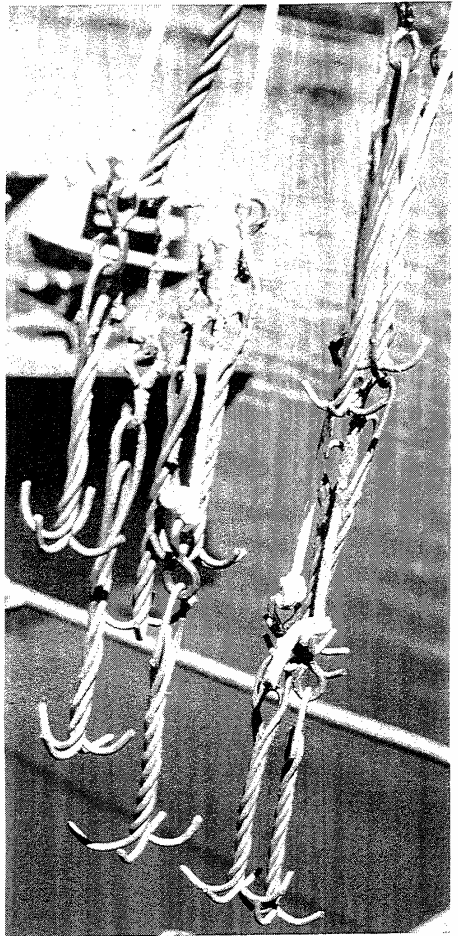
Figure 115: Clam or "crowfoot" hooks.

Figure 116: Wabash River clam boats with stored crowfoot bars and hooks.

Phytoplankton and the Wabash River Ecosystem

Interactions between the biota and the physical and chemical environment are sporadic, complex, and poorly perceived in the highly variable environment of most rivers. The entire Wabash River ecosystem is strongly influenced by phytoplankton, especially during the summer months, but there are few data to support that contention. Our knowledge about this particular group is disparate to its ecological importance.

Phytoplankton constitutes by far the most important producer group in the middle Wabash River. Water willow beds are well represented in the upper river, but they become scarce in the lower two-thirds. Periphyton is severely limited because of the turbidity of the water, but is no doubt important in shallow areas which receive light.

The Indiana Department of Environmental Management, formerly a Division of the Indiana State Board of Health, began collecting phytoplankton from various river stations on a monthly schedule in 1971 (Indiana State Board of Health 1957-85; Indiana Department of Environ-mental Management 1986-90). The basic spatial pattern of phytoplankton density and the influence of discharge is shown best at eight stations along the Wabash River during the low-flow summers of 1977 and 1988 (Figure 117). During the summer the density of phytoplankton in the upper river is relatively low, but it increases dramatically as the river flows southward and reaches its highest density levels downriver from Lafayette, Indiana.

The summer of 1977 followed an unusually dry winter and spring. Algal densities were very high in June and July, but but decreased substantially thereafter when the river discharge increased in August and September. Usually the phytoplankton community is dominated by diatoms, but green algae were as abundant as diatoms in 1988. Phytoplankton density is typically high during the warmer months, May through October. Low densities are found during the winter months because of low temperatures and during the spring because of high discharge rates.

During the summers of 1981 and 1982 an interdisciplinary team conducted a study of the dissolved oxygen (DO) status of the middle Wabash River (Bridges et al. 1986). Phytoplankton densities ranged from 20,000 to 120,000 cells/Ml, chlorophyll $\underline{a}$ ranged from 18 to 247 ug/L, pheophytin $\underline{a}$ was 6.5 to 51 ug/L, gross primary productivity (GPP) ranged from 70 to 850 mg $C/m^2/h$, and net primary productivity was 90 to 784 mg $C/m^2/h$. Turbidity was high and the depth of the euphotic zone was only 0.2 to 1.2 m.

Estimates were also made of point-source biological oxygen demand (BOD), sediment oxygen demand (SOD), and chemical oxygen demand (COD). All of this information was used to estimate the dissolved oxygen deficit (DOD) using a version of the DIURNAL computer model (HydroQual, Inc. 1984). The DOD is calculated as the saturation concentration at the prevailing temperature minus the actual dissolved oxygen concentration (Smith et al.

1987). This model projected low-flow DOD values of 2.0 to 2.5 mg O/L from Delphi, Indiana to Montezuma, Indiana and then increasing values to about 4.0 mg O/L from Terre Haute, Indiana to Merom, Indiana.

Phytoplankton respiration was estimated to cause 50-60% of the dissolved oxygen deficit in the upper study section and about 70% downriver from Terre Haute, Indiana. The second largest source, carbonaceous BOD or CBOD which entered the river from multiple point sources, accounted for only about 10% of the DOD in the upper reaches and over 15% downriver from Terre Haute, Indiana.

Sediment oxygen demand (SOD) was estimated to be the third largest oxygen sink, and nitrogenous BOD and other substances also contributed to a minor degree.

Phytoplankton and other organic substances may indirectly affect the fish community during low flows in some parts of the river by reducing dissolved oxygen concentrations (Parke and Gammon 1986). River morphology, large algal populations sustained by high nutrient inputs, and

thermal loading from an electric generating station interact to produce low dissolved oxygen concentrations in a 9.6 km section of river dammed by gravel from Sugar Creek.

When flows diminished to about 1,500 cfs there was a sharp increase in phyto-plankton density with chlorophyll $\underline{a}$ increasing from about 160 ug/L to nearly 230 ug/L. Significant amounts of suspended solids settle to the bottom as the water passes through the ponded segment. Chlorophyll $\underline{a}$ decreased to less than 150 ug/L and total suspended nonfiltrable solids decreased from 80 mg/L to about 50 mg/L. Secchi disk transparency increased as suspended materials settled out and SOD increased. In 1977 a depression in dissolved oxygen concentration led to avoidance of this areas of the river by fish (Gammon and Reidy 1981) and caused fish kills in 1983 and 1986.

The dissolved oxygen sag curve was reexamined in 1988, both with and without the Cayuga Electric Generating Station operational (EA Engineering 1990). It was concluded that a DO sag occurs naturally in the Sugar Creek Pool because of its morphology and high summer temperatures.

No/ml x 1000   m3/sec

June   July   August   Sept.

1977

200
175
150
125
100
75
50
25
0

1000

100

10

4 3 3 3 3 2 2 2 1   4 3 3 3 3 2 2 2 1   4 3 3 3 3 2 2 2 1   4 3 3 3 3 2 2 2 1
0 9 6 4 0 4 2 0 2   0 9 6 4 0 4 2 0 2   0 9 6 4 0 4 2 0 2   0 9 6 4 0 4 2 0 2
9 9 0 4 3 5 8 7 8   9 9 0 4 3 5 8 7 8   9 9 0 4 3 5 8 7 8   9 9 0 4 3 5 8 7 8

River Mile

■ Blue-green   ▨ Green   ▧ Diatoms
▨ Others   — Discharge

No/ml x 1000   m3/sec

June   July   August   Sept.

1988

150
125
100
75
50
25
0

100

10

4 3 3 3 2 2 2 1   4 3 3 3 2 2 2 1   4 3 3 3 2 2 2 1   4 3 3 3 2 2 2 1
0 4 1 0 5 4 1 3   0 4 1 0 5 4 1 3   0 4 1 0 5 4 1 3   0 4 1 0 5 4 1 3
9 7 6 3 6 0 8 0   9 7 6 3 6 0 8 0   9 7 6 3 6 0 8 0   9 7 6 3 6 0 8 0

River Mile

■ Blue-green   ▨ Green   ▧ Diatoms
▨ Other   — Discharge

Figure 117: Spatial pattern of phytoplankton density in the Wabash River during the summers of 1977 and 1988.

EVALUATION OF THE EFFECT OF CITIES AND INDUSTRIES ON THE FISH COMMUNITIES OF THE MIDDLE WABASH RIVER

The physical and chemical environment of rivers is highly variable over space and time and resident fishes must necessarily adapt to these changes physiologically and/or behaviourly or perish. Natural environmental changes may occur suddenly such as increased water velocity and turbidity and decreased temperature and dissolved oxygen when flooding occurs after a heavy rain. Man's activities may also cause sudden spatial changes as the result of raw industrial or domestic wastes entering the river. Chronic environmental changes in entire river systems may occur when the natural vegetation of a drainage basin is replaced by row-crop agriculture or when large areas are mined.

This section evaluates the effects of important local sources of environmental alteration such as electric generating plants, population centers, and industries using multivariate statistical analysis of fish species catch data and changes over space and time as indicated by the composite index of well-being (Iwb). A detrended correspondence analysis (DCA) (Ter Braak 1987) was used to examine the modifications in fish community structure. The sections of river examined included (a) the Wabash River Electric Generating Station (Reach 9), (b) the Cayuga Electric Generating Station (Reach 6), (c) the Eli Lilly plant located north of Clinton, Indiana (located at the boundary of Reaches 7 and 8), (d) the Lafayette-West Lafayette metropolitan area (Reach 2), and (e) the Terre Haute metropolitan area (Reach 10) (Figure 118).

Input data in all cases consisted of raw species abundance (no/km) of the 33 most common and/or important species of fish in the middle Wabash River, as shown in Table 11. Most of the selected species are found throughout the middle Wabash River although some may be more abundant in the upper section and others more common the lower section. The species list included gizzard shad, the most common species taken by electrofishing. However, the ordination pattern produced when that species was eliminated from the analyses was much clearer than it was when shad were included.
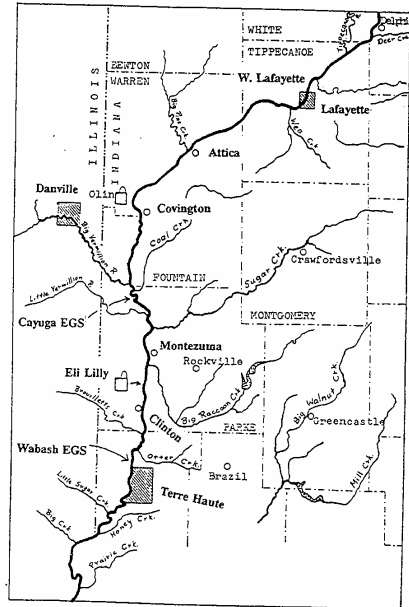
Figure 118: Location of point-sources evaluated with detrended correspondence analysis (DCA).

The population abundance of gizzard shad fluctuated erratically from year to year for varied and different reasons. Weather patterns and local hydrological conditions were influential some years. For several years after 1984 the increased abundance of predator fishes effectively reduced gizzard shad to low population densities.

The detrended correspondence analysis patterns produced by catch data transformed to natural logarithms were essentially similar to patterns produced using untransformed data. Therefore, all DCA analyses were performed using raw relative density values (No/km).

A view of the Wabash River from the bluffs at Merom, Indiana

Table 13: Species included in the detrended correspondence analysis (DCA).

Shovelnose sturgeon - *Scaphirhynchus platorynchus* (Rafinesque)
Longnose gar - *Lepisosteus osseus* (Linnaeus)
Shortnose gar - *Lepisosteus platostomus* Rafinesque
Goldeye - *Hiodon alosoides* (Rafinesque)
Mooneye - *Hiodon tergisus* Lesueur
Skipjack Herring - *Alosa chrysochloris* (Rafinesque)
Gizzard shad - *Dorosoma cepedianum* (Lesueur)
Carp - *Cyprinus carpio* Linnaeus
Silver chub - *Macrhybopsis storeriana* (Kirtland)
Emerald shiner - *Notropis atherinoides* Rafinesque
Northern river carpsucker - *Carpiodes carpio* (Rafinesque)
Quillback carpsucker - *Carpiodes cyprinus* (Lesueur)
Highfin carpsucker - *Carpiodes velifer* (Rafinesque)
Blue sucker - *Cycleptus elongatus* (Lesueur)
Northern hog sucker - *Hypentelium nigricans* (Lesueur)
Smallmouth buffalo - *Ictiobus bubalus* (Rafinesque)
Bigmouth buffalo - *Ictiobus cyprinellus* (Valenciennes)
Silver redhorse - *Moxostoma anisurum* (Rafinesque)
River redhorse - *Moxostoma carinatum* (Cope)
Black redhorse - *Moxostoma dequesnei* (Lesueur)
Golden redhorse - *Moxostoma erythrurum* (Rafinesque)
Shorthead redhorse - *Moxostoma macrolepidotum* (Lesueur)
Channel catfish - *Ictalurus punctatus* (Rafinesque)
Flathead catfish - *Pylodictis olivaris* (Rafinesque)
White bass - *Morone chrysops* (Rafinesque)
Longear sunfish - *Lepomis megalotis* (Rafinesque)
Smallmouth bass - *Micropterus dolomieu* Lacepede
Spotted bass - *Micropterus punctulatus* (Rafinesque)
Largemouth bass - *Micropterus salmoides* (Lacepede)
White crappie - *Pomoxis annularis* Rafinesque
Black crappie - *Pomoxis nigromaculatus* (Lesueur)
Sauger - *Stizostedion canadense* (Smith)
Walleye - *Stizostedion vitreum* (Mitchill)
Freshwater drum - *Aplodinotus grunniens* Rafinesque

The Effects of Cayuga and
Wabash Electric Generating Stations

Five electric generating stations (EGS) were located directly on the Wabash River between Delphi, Indiana and Merom, Indiana during the period of study, all of them coal-fired and employing once-through cooling. Only four of these remain operational at the present time.

PSI-Energy operates two electric generating stations in the middle Wabash River, (1) the Cayuga EGS which is located between Newport, IN and Cayuga, IN at RKm 402 (RM 250) in Vermillion County and (2) the Wabash EGS which is located upriver from Terre Haute, IN located at RKm 346 (RM 215) in Vigo County. PSI-Energy's Dresser EGS, rated at 149 Megawatts (MW) and located at Rkm 330 (RM 205) south of Terre Haute, was operational until 1975.

Further downriver at Rkm 295 (RM 183) the Breed EGS (420 MW) is operated by the Indiana and Michigan Electric Company. It discharged water elevated about 5°C above ambient temperatures. Breed EGS was scheduled to close in Spring of 1994. Still further downriver is the Hutsonville EGS (Central Illinois Public Service), a four-unit plant rated at 214 MW and located about 3 km (2 miles) north of Hutsonville, Illinois.

The Wabash River EGS is rated at 970 Megawatts (MW) with a maximum heat rejection of about 5.0×10^9 Btu/h (average monthly heat rate = 10,063 Btu/kWh). The maximum pumping rate is approximately 30 m^3/s. Operating since 1956, it increased its capacity in 1968. One unit will soon utilize steam from a coal gasification process. The Wabash River is about 120 m wide and 2.7 m

deep near the Wabash EGS during normal summer flows. Near-shore substrates consist of mud mixed with sand changing to sand and gravel toward the middle of the river. The discharge is located immediately downriver from the intake embayments and is separated from the river water by a 120 m long concrete "cell structure" (Figure 119). The discharge water is heated 7 - 9°C over ambient intake water. When river discharge is low (< 230 m^3/s or 8,000 cfs) the effluent is separated from river water by the cell structure. After clearing the cell structure, the heated plume moves diagonally to the east shore and mixes quickly with the river water, especially after passing over a shallow riffle located about 1.2 km (0.75 m) downriver. At higher flows the river water passes over the top of the cell structure, mixes quickly with the heated discharge, and the heated plume moves along the west shore for some distance downriver.

The Cayuga EGS began operating in October 1970 with a 500 MW unit. A second 500 MW unit started up in May 1972. About 37.3 m^3/s of cooling water is pumped to remove about 4.88×10^9 Btu/h heat (average monthly heat rate = 9600 Btu/kWh). Operating at full capacity this EGS is theoretically capable of using 100% of the river. The intake is located near the head of a large horseshoe bend in the river which subsequently receives heated discharge water nearly 3.7 km (2.3 m) downriver (Figure 120). The heated discharge is then returned to a canal located close to the intake structure and flows 1.2 km (0.75 m) to finally enter the Wabash River at the lower end of the horseshoe bend. A low wier located midway along the canal aids in pumping water into two small cooling towers.

Figure 119: The Wabash Electric Generating Station and location of fish collecting stations.

Figure 120: The Cayuga Electric Generating Station and location of fish collecting zones.
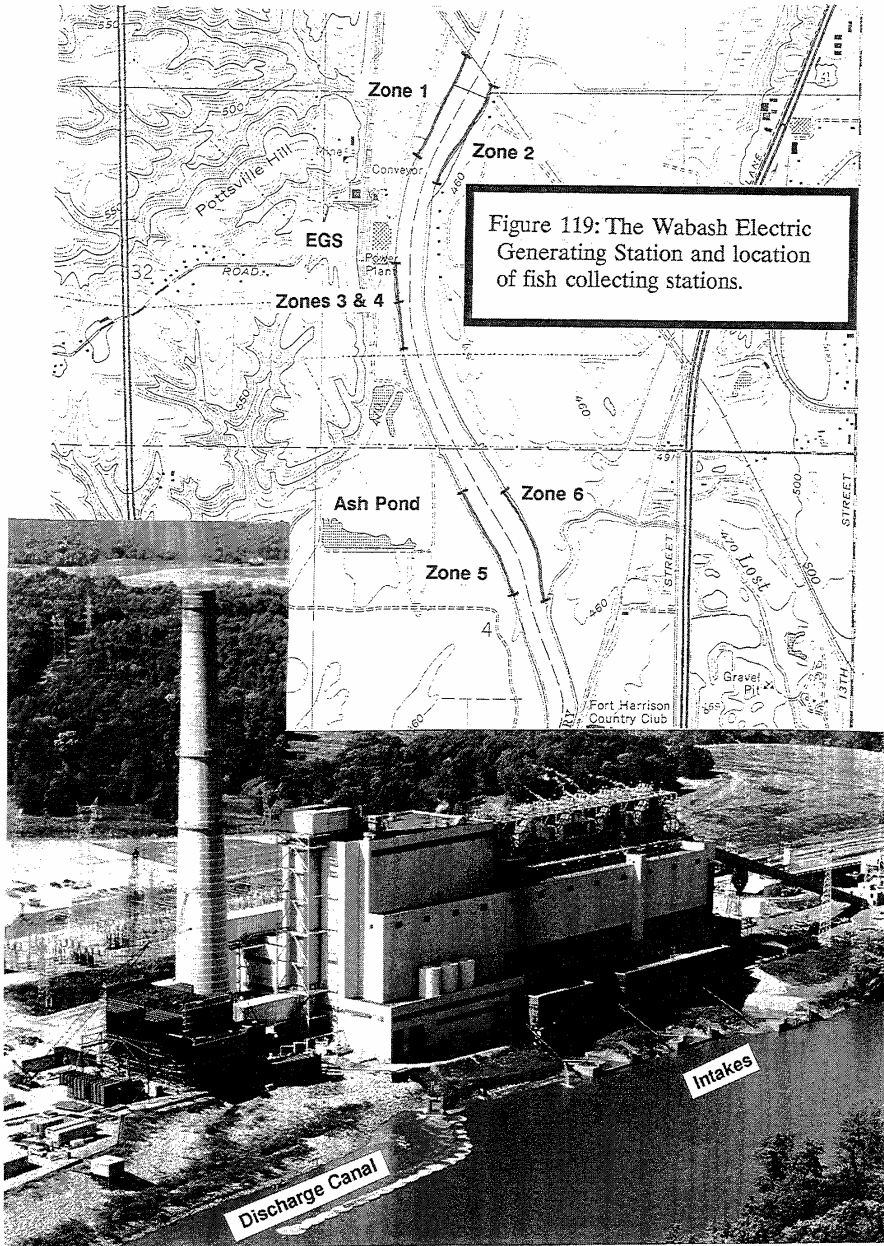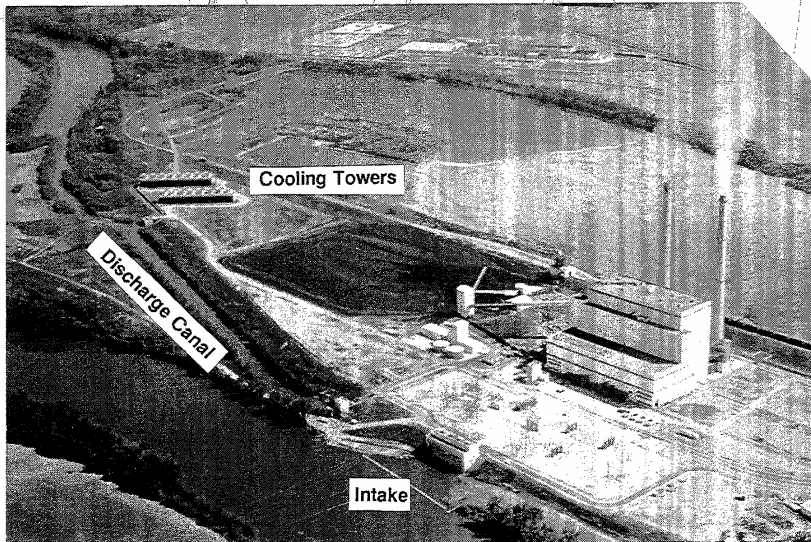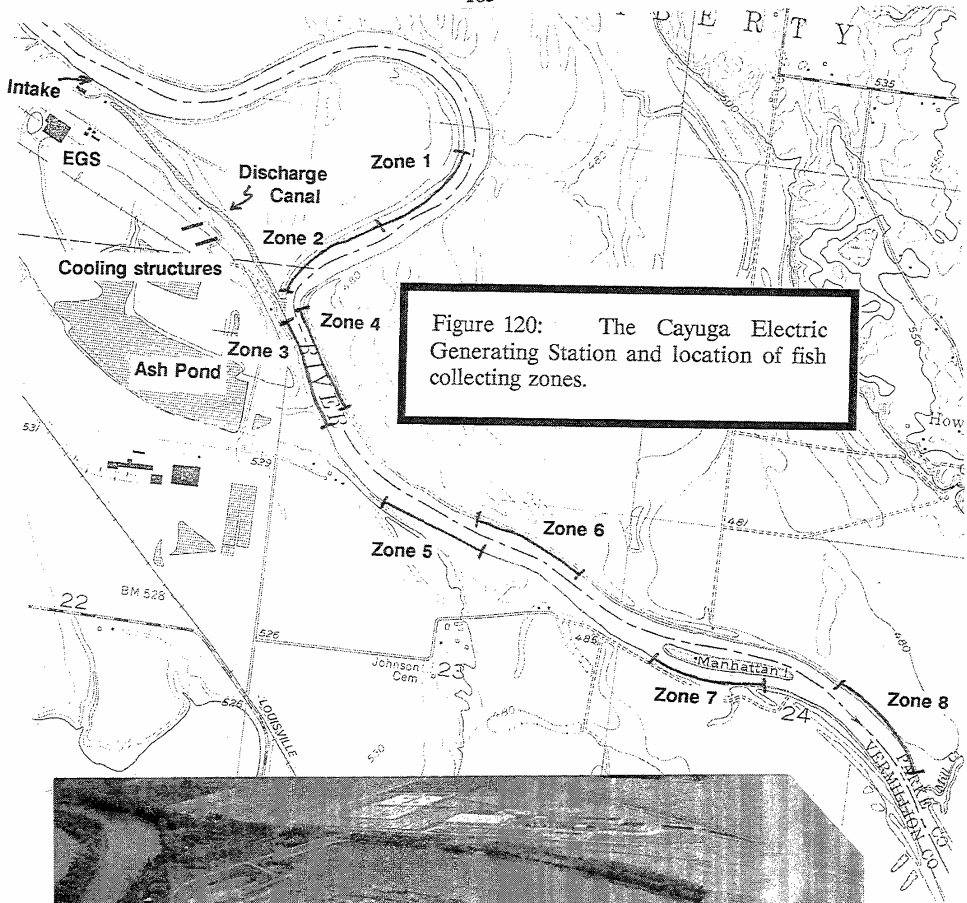
The river at the Cayuga EGS is about 117 m wide and offers a wide variety of aquatic habitats from slow-moving, sandy-bottom shelves to fast, deep chutes. Woody cover is common, but aquatic vegetation is absent. The thermal plume adheres closely to the west bank for about 3 km before mixing with river water (Bartolucci, Hoffer, and Gammon (1973). Both the Wabash River EGS and the Cayuga EGS use intermittent chlorination to control fouling organisms and scale carbonates are removed with HCl about twice annually.

The results of river studies at the Wabash and Cayuga EGSs since 1967 have been summarized in numerous special and annual reports, 11 published documents, and 8 M.A. theses which are listed in the Literature Cited section. The following summarizes some of the major activities and findings.

Early studies included field determinations of temperature preference in the immediate vicinity of the Wabash River EGS using several collecting methods (Gammon 1973, 1982). Hoop-nets with 3.8 cm bar-mesh fished without wings or leaders and D.C. electrofishing collections were made in three sections of river. These sites were selected because of their distinct thermal regimes ranging from an cool, upriver ambient section to hot effluent in the discharge canal with an intermediate mixed thermal zone. A Smith-Root Type VI electrofisher producing 400 to 600 V DC at 5.5 amps was mounted on a 5 m Jon-boat and used for the electrofishing activities.

Raw catch data were converted to relative catch rates to remove variations in annual abundance and gear efficiency by dividing each lower catch value by the

highest catch value. These relative catch values were then plotted as a function of temperature (Gammon 1973). Provided with free access to a range of thermal conditions, fish will normally congregate in a "preferred" thermal zone which is dependent upon acclimation temperature and species attributes. Increasing the acclimation temperature will elevate the preferred temperature, but only as high as an *upper preferred temperature* or *final preferendum* (Fry 1969). This final preferred temperature appears to be physiologically optimal for the species in terms of growth, movement, food conversion, etc. Avoidance follows further elevations in temperature or, if cooler water is not found, death at a thermal level called the *upper ultimate incipient lethal temperature* or critical thermal maximum (TMax).

The preferred field temperatures of resident species in the Wabash River and Ohio River were compared to published upper preferenda and upper ultimate incipient lethal temperatures determined in controlled laboratory studies (Gammon 1982). There was generally good agreement of values determined through field and laboratory studies. No mortality was observed due to thermally lethal temperatures because behavioral avoidance effectively operated and caused fish to move out of thermally lethal water.

Preoperational assessments of the fish community at the Cayuga electric generating station began in 1968, three years before the first 500 MW unit began generating. A river segment 5.2 km (3.25 miles) long was subdivided into 8 collecting zones. After Cayuga began operating three of these zones were strongly influenced by the heated effluent and two other zones were sporadically affected. Catch statistics for

common species and community attributes before (1968-71) and after (1972-81) full start-up of Cayuga EGS were also examined (Gammon 1983). The population responses generally followed predictions based on thermal preferenda with population decreases in thermally sensitive species such as smallmouth bass, redhorse, sauger, mooneye, and goldeye and population increases for thermally tolerant species such as drum, carpsucker, gizzard shad, carp, and flathead catfish.

The calculated Iwb values at both Wabash EGS and Cayuga EGS have fluctuated considerably since 1968, as have the Iwb values at Reach 1, the "ambient" section of river located between Delphi, Indiana and Lafayette, Indiana, (Figure 121). All of the collecting zones at both electric generating

stations were included in this example, heated zones as well as unheated zones.

The changes in the fish community following start-up at the Cayuga EGS resulted in a substantial local decrease in the Iwb values. The fluctuations were similar at both electric generating stations after 1970, but the amplitude was more accentuated at the Wabash River EGS than at Cayuga EGS. Iwb values were especially low during the low-flow summers of 1983, 1988, and 1991 and after the 1993 flood.

The overall pattern of Iwb change in Reach 1 was generally similar to that of the electric generating stations (Reaches 6 and 9). Iwb values here were also notably depressed in 1983, 1991, 1993, and 1994, but not during 1988.
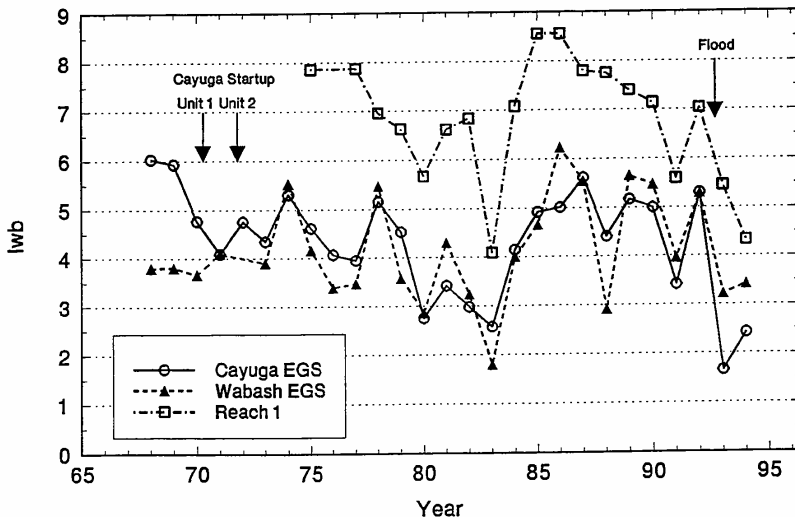
Figure 121: Changes in mean composite index of well-being (Iwb) values
at Wabash EGS, Cayuga EGS, and Reach 1.

The input for the DCA results included the catch data from all 8 zones at Cayuga (Reach 6) combined, together with data from Reach 5 upriver, Reach 7 downriver, and Reach 1. Catches in Reach 1, extending from Delphi, Indiana to Lafayette, Indiana were included as a reference or ambient data set. However, collections of fish from Reach 1 date back only to 1975, hence, the time periods do not exactly coincide.

The fish populations at the Cayuga EGS construction site during 1968, 1969, and 1970 were quite homogeneous as shown by the DCA pattern (Figure 122). They changed only slightly in 1971 after the first 500 MW unit began operating. There is also a surprisingly good correspondence at this time and place with the fish populations in Reach 1 of 1975-93 despite the different time periods. By 1972, however, when both Cayuga EGS generating units were operational, the pattern shifts downward and to the right as indicated by the arrow. The period 1973-85 is marked by great annual variability with the extremely poor catches of 1983 displaying the greatest deviation.

Improvements in the fish community throughout the river began in 1984 and peaked in 1985-86. Prior to 1987 the Cayuga EGS discharge water, elevated about 8° C (14° F), was discharged directly into the Wabash River, although the cooling towers were used sporadically to moderate the temperature of discharge water.

Beginning in 1987, however, the mode of operation at the Cayuga EGS was altered by agreement with the Indiana Department of Environmental Management. When the water temperature of the Wabash River increased to the level of 24.5° C (78° F), the

heated discharge water was pumped from the discharge canal into the cooling towers. This was a continuous operation through the hot summer months and was discontinued only when the ambient water temperatures declined again in the fall. Beginning in 1991 the cooling towers started operating when the water temperature reached 24.5°C (78°F) **and** the river flow decreased less than 4000 cfs.

One interesting question is whether this change in operation had any beneficial effect on the fish community. One important indication of improvement was noted in 1987, the very first year of the modified operation; the Iwb value of Reach 6 increased while in all other Reaches it declined. This increase in Iwb was accompanied by the return of several thermally sensitive species after a long absence.

The DCA indicates clearly that there was, indeed, an improvement in the fish community following 1987 (Figure 122). This recovery is indicated by a significant shift of the fish community toward the preoperational status for the years 1987 through 1992. As indicated previously, the 1993 data was severely limited by high discharge rates and limited collecting effort which may account for the displacement of that data point.

Table 14 examines the changes in catch rates at the Cayuga EGS for three periods. The preoperational period (1968-71) includes the first post-operational year 1971 because the resident fish community was similar to those of the previous three years. The postoperational period extends from 1972 through 1986. The modified post-operational period includes 1987 through 1992, but not 1993 data because of its limitations. It should be emphasized that this period includes two drought years.
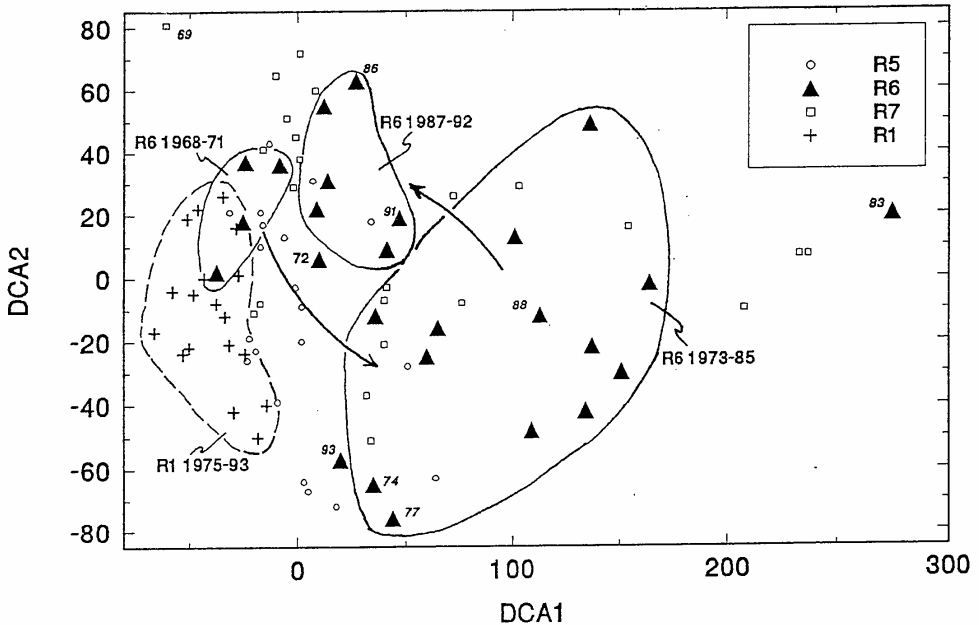
Figure 122: Plots of the first two axes of detrended correspondence analysis (DCA) of species abundance (no/km) at the Cayuga Electric Generating Station (Reach 6) and data from Reaches 1, 5, and 7.

The fish listed in Table 14 include the more common and important species of the community which are divided into four groups separated by dashed lines. Carp and flathead catfish both increased numerically after Cayuga EGS started operating. However, the catch rates of both species have decreased since 1987 under conditions of modified operation.

The second group includes seven species of fish whose catch rates increased after Cayuga EGS became operational and increased still further under the modified operation. They also include blue sucker, drum, gizzard shad, channel catfish, shovel-

nose sturgeon, buffalofish, and white bass. Some, but not all, of these species experienced large increases in abundance throughout the river recently. Nevertheless, it is possible that the modified operation was advantageous to them in thermally elevated sections of river.

The third group includes smallmouth bass, shorthead redhorse, silver redhorse, spotted bass, mooneye, goldeye, shortnose gar, longnose gar, and northern river carpsucker. Most of these species, but not all, are less thermally tolerant than the preceding groups. All of these species declined in abundance after Cayuga EGS

began operating full-time. Additionally, all of them increased in numeric abundance after 1986, indicating improved environmental conditions in the vicinity of the Cayuga EGS as well as throughout the Wabash River.

The last group includes some of the most thermally sensitive species of fish: longear sunfish, black and white crappie, skipjack herring, golden redhorse, and sauger. All of these species declined in abundance after Cayuga EGS began operating and the modified operating procedures did nothing to enhance their numbers in the vicinity of the power plant. Sauger and skipjack herring populations throughout the Wabash River appear to have grown smaller in recent years.

One consequence of the altered operation at the Cayuga EGS is that the fish community is now much more similar to the community in Reach 5, the segment of river upriver from Cayuga EGS. In addition, the change in operation at Cayuga EGS has also improved the fish populations in Reach 7 downriver where the recent fish communities approach preoperational status.

The Wabash EGS (Reach 9) was already operational when we began studying the river in 1967. Fish collections using DC electrofishing date from 1968. Regular electrofishing collections upriver at Reach 8 and downriver at Reach 10 (Terre Haute, Indiana) began in 1973. The results of the DCA are based on catch data from Reaches 8, 9, and 10, again with data from Reach 1 serving as a reference or ambient community. The DCA indicates that the fish communities in R8, R9, and R10 are very similar to one another, but that as a group they are quite different from the community of Reach 1 (Figure 123). The fish community in R8 was

more variable over time than the other two Reaches. Reach 10, the Terre Haute, Indiana area, exhibited the least temporal variability among the fish populations in these three Reaches. Nevertheless, the fish populations in R10 differed most from those of R1.

Figure 124 contains the same DCA plots as the previous figure, but groups the data points for Reach 9, the Wabash River EGS, into two time periods, a) the operational 1968-88 period and b) the modified operational 1989-92 period.

The Wabash River EGS lacks cooling facilities but it began operating under a maximum thermal ceiling of 32.2°C (90°F) beginning in September 1988, as measured at the Indiana Highway 63 bridge located 3 km (2 miles) downriver from the plant. When the river temperature reaches that limit, the EGS reduces its generating capacity and, therefore, the amount of heat delivered to the Wabash River.

The fish communities near the Wabash River EGS after initiating the modified operating procedure were very similar to those which preceded them, as shown by the mostly overlapping patterns in Figure 122. From the DCA alone it appears that this change in plant operation had little benefical impact on the fish community, unlike the situation at Cayuga EGS. However, an examination of catch rates of fish before and after the operational change indicates that most species populations were much more common after 1988 (Table 13). However, carp, buffalofish, and crappie abundance was unchanged, while goldeye, skipjack herring, golden redhorse, and sauger populations declined.

Table 14: A comparison of catch rates of fish (No/km) at the Cayuga Electric Generating
Station during the following periods: a) preoperational (1968-71), b) postoperational
(1972-86), and c) modified postoperational (1987-92).

Species	1968-71	1972-86	1987-92
Carp	0.546	2.026	1.471
Flathead catfish	0.083	1.634	1.426
Blue sucker	0.025	0.046	0.235
Freshwater drum	0.105	0.127	0.662
Gizzard shad	12.494	30.885	41.515
Channel catfish	0.148	0.198	0.382
Shovelnose sturgeon	0.018	0.046	0.059
Buffalofish	0.116	0.138	0.544
White bass	0.166	0.320	0.515
Smallmouth bass	0.166	0.023	0.103
Shorthead redhorse	1.037	0.277	0.529
Silver redhorse	0.434	0.148	0.338
Spotted bass	0.155	0.090	0.147
Mooneye	0.123	0.071	0.088
Goldeye	0.206	0.164	0.206
Shortnose gar	0.752	0.551	1.103
Longnose gar	0.614	0.565	1.250
Northern river carpsucker	0.932	0.666	2.132
Longear sunfish	0.163	0.046	0.044
Crappie	0.120	0.109	0.029
Skipjack herring	0.155	0.150	0.118
Golden redhorse	0.857	0.364	0.176
Sauger	0.647	0.189	0.147

Total number of catches =	215	514	136
Total km electrofished =	277	434	68

Figure 123: Plots of the first two axes of detrended correspondence analysis (DCA) of species abundance (no/km) at the Wabash EGS (R9) together with flanking Reaches R8 and R10, and R1 for comparison.
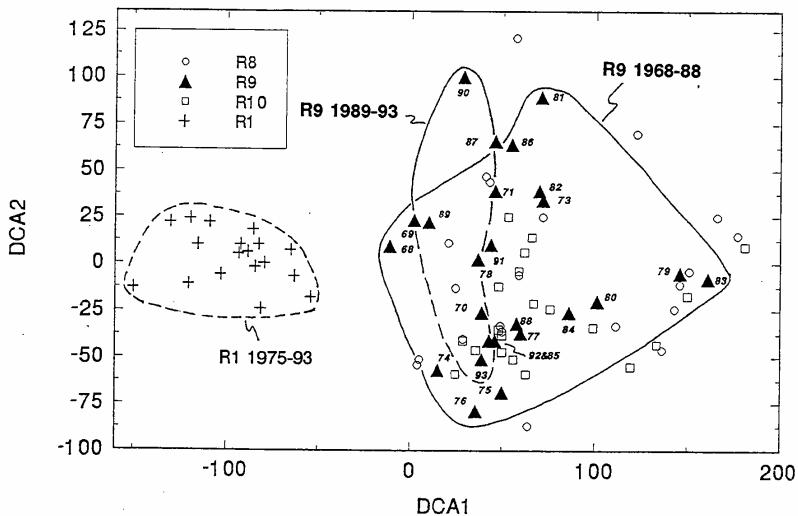
Figure 124: Same DCA plot as the previous figure, but grouping the data at the Wabash EGS (Reach 9) into two time periods: 1968-88 and 1989-93.

Table 15: A comparison of catch rates of fish (No/km) at the Wabash River EGS
during two time periods: a) 1968-88, and b) modified operation 1989-92.

Species	1968-88	1989-92
Carp	1.891	2.121
Flathead catfish	0.770	2.121
Blue sucker	0.029	0.394
Freshwater drum	0.170	0.818
Gizzard shad	15.658	38.697
Channel catfish	0.510	1.000
Shovelnose sturgeon	0.024	0.450
Buffalofish	0.178	0.182
White bass	0.244	0.758
Smallmouth bass	0.008	0.091
Shorthead redhorse	0.058	0.273
Silver redhorse	0.029	0.121
Spotted bass	0.088	0.182
Mooneye	0.088	0.364
Goldeye	0.475	0.303
Shortnose gar	1.054	1.879
Longnose gar	0.906	2.333
Northern river carpsucker	0.783	1.818
Longear sunfish	0.027	0.273
Crappie	0.056	0.061
Skipjack herring	0.337	0.212
Golden redhorse	0.037	0.030
Sauger	0.149	0.091

Total number of catches =   418   66
Total km electrofished   =   377   33

The Effect of the Eli Lilly Plant
at Clinton, Indiana

Eli Lilly and Company operates two large pharmaceutical facilities on the middle Wabash River, the Tippecanoe Plant located on the south edge of Lafayette, Indiana at Rkm 497 (RM309) and the Clinton Plant located between Montezuma and Clinton, Indiana at Rkm 374 (RM232). The effects of the Clinton Plant are presented here. Analysis of data near the Tippecanoe Plant will be considered as part of the entire Lafayette/West Lafayette area.

Two data sets are available to evaluate the effect of the effluent from Eli Lilly's Clinton facility on the Wabash River fish community: 1) the regular annual electrofishing collections of fish in adjacent upriver and downriver zones which flank the effluent canal and 2) the results of special electrofishing studies conducted in 1984 and 1991.

The locations of the collecting sites at the Clinton Plant are shown in Figure 125. The same sites were used both in 1984 and 1991 except for the addition in 1991 of site E where the new effluent canal will be located. The effluent canal was relocated during the summer of 1994.

Data from regular electrofishing collections at the first sites upriver and downriver from the effluent canal were examined for the years 1973 through 1992 with the DCA of catch data (no/km) upriver and downriver from the effluent canal. Data from the years 1979 and 1993 were excluded because of insufficient collecting effort. The arrows shown in Figure 124 indicate the relative differences in the fish populations upriver and downriver from the plant. The

longer the arrow the greater the difference between upstream and downstream populations.

Assuming that effluent volume and toxicity remained fairly constant over time, any negative impacts to the fish community should be greater during low-flow periods than during periods when river discharge was "normal" or high. Therefore, population differences between upriver and downriver stations should be greater during drought years.

In 1977 and 1988 the populations upriver and downriver from the effluent canal differed substantially (Figure 124). However, the differences were no greater in 1991 than during other high or normal flow summers. In 1977, the first upriver station electrofished was located at RM335 (A) immediately above the mouth of Big Raccoon Creek (Figure 123). Catches downriver from the effluent canal at Summit Grove (RM231 or G) included longear sunfish, spotted bass, smallmouth buffalo, blue sucker, longnose and shortnose gar while those upriver included bowfin and goldeye in addition to other species common to both locations (Table 16). Therefore, the community downriver appeared subjectively to be somewhat "better" than the community upriver. Values of various community parameters, however, were very similar.

In 1988 stations D and G constituted the flanking collecting sites (Figure 123). Catches upriver were considerably more diverse than those downriver and included channel catfish, white bass, two species of *Moxostoma*, and particularly large numbers of

northern river carpsuckers in addition to species common to both sites (Table 16). Community values were substantially higher upriver than downriver as a result.

Fish populations above and below the plant were quite similar in 1991 when the river flow was also extremely low. However, all community values were higher downriver from the effluent canal than upriver.

Thus, the DCA yielded results which are inconsistent. In the absence of preoperational data there is no convincing evidence that the effluent from the Eli Lilly Clinton plant consistently exerts a negative impact on the fish community of the adjacent Wabash River.

Special electrofishing collections were made during the periods August 6-15, 1984 and July 18 to August 14, 1991 in order to examine more closely the effect of Eli Lilly - Clinton effluents on the Wabash River fish community. As indicated previously, 10 sites were sampled by electrofishing 3 times in 1984 and 11 sites were electrofished 3 times each during 1991. Catch data (no/km) for all sites and for both years were analyzed by DCA. The results of these studies which compare upriver catches with downriver catches are summarized in Figure 127.

Variability among stations was considerably greater in 1991 than it was in 1984. In 1984 the downriver populations were very similar to those upriver from the Eli Lilly Clinton plant as indicated by the intersecting hypervolumes. In 1991 there was less similarity, but still an intersecting of the above-below hypervolumes. Station G, immediately downriver from the effluent canal, and station I deviated most from populations upriver. The catch data indicates somewhat fewer species at these two sites than elsewhere, but nothing otherwise unusual.

Composite index of well-being (Iwb) profiles for 1984 and 1991 are shown in Figure 128. The higher Iwb values for the 1991 catch clearly reflect the improved fish community found in the Wabash River in recent years. Locally weighted least-squares linear regression (Lowess) lines suggest that the fish communities downriver from the effluent canal were depressed in 1984, but not in 1991. The summer of 1984 was not a particularly low-flow summer (Figure 16) and the effluents for Eli Lilly - Clinton would be more likely to have dispersed and been diluted during that year than during 1991. Here, again, the results are inconclusive and inconsistent. Overall, there is no convincing evidence that the Eli Lilly-Clinton plant has had any negative impact on the nearby fish community of the Wabash River.
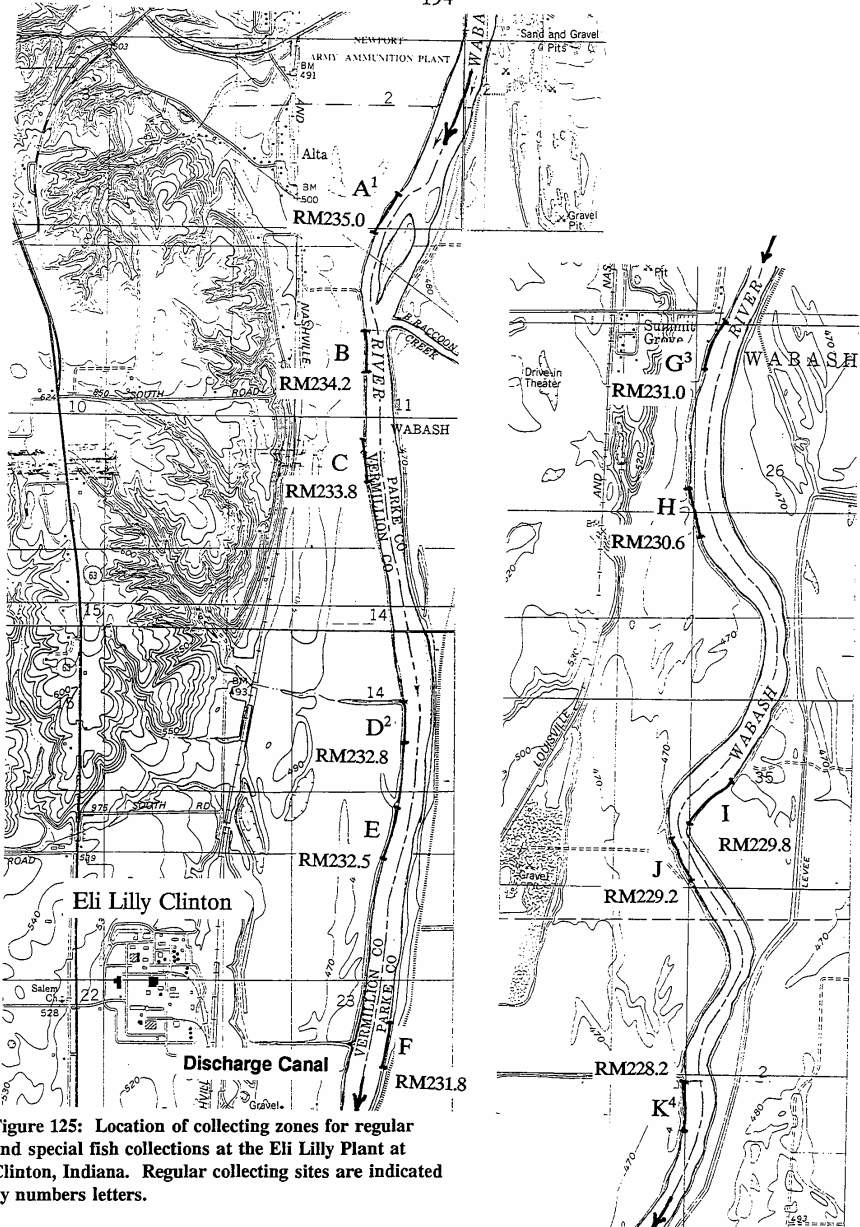
Figure 125: Location of collecting zones for regular and special fish collections at the Eli Lilly Plant at Clinton, Indiana. Regular collecting sites are indicated by numbers letters.
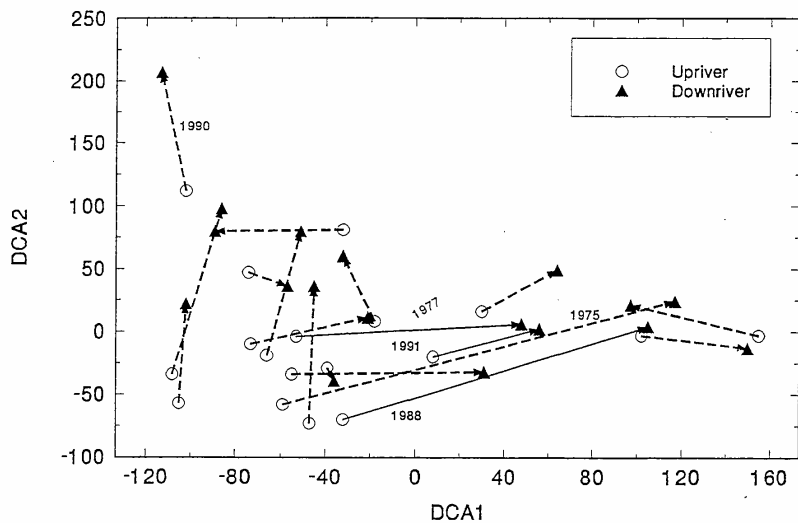
Figure 126: Plots of the first two axes of detrended correspondence analysis (DCA) of species abundance (no/km) at regular upstream and downstream collecting station closest to the Eli Lilly Clinton effluent canal.
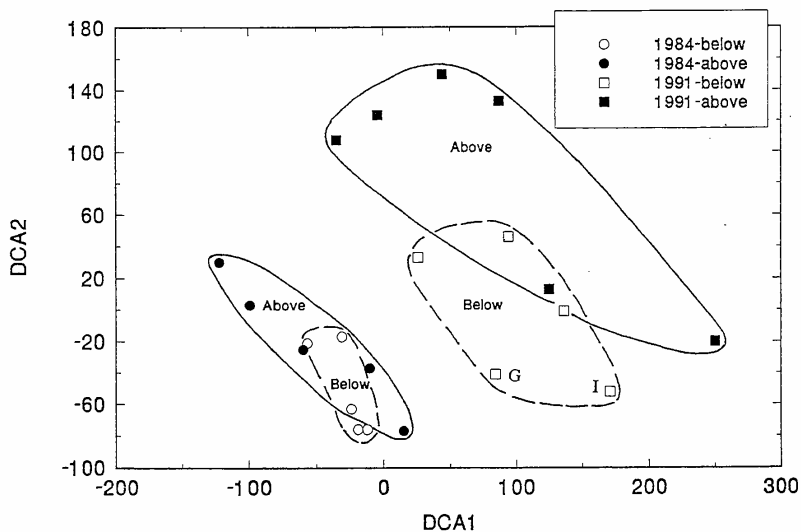
Figure 127: Plots of the first two axes of detrended correspondence analysis (DCA) of catch data taken in special studies in 1984 and 1991.

Table 16: Electrofishing catch rates (No/km) above and below the Eli Lilly - Clinton effluent canal during the drought summers of 1977, 1988, and 1991.

Species or Community Parameter	1977		1988		1991	
	Above (A)	Below (G)	Above (E)	Below (G)	Above (E)	Below (G)
Longnose gar	-	1.333	-	-	-	-
Shortnose gar	-	0.333	0.667	0.667	-	0.667
Gizzard shad	29.333	19.333	2.000	3.333	4.667	1.333
Goldeye	0.333	-	-	-	-	0.667
Channel catfish	-	-	1.333	-	-	-
Flathead catfish	2.000	0.667	4.000	8.000	3.333	9.333
White bass	-	-	1.333	-	-	1.333
Freshwater drum	1.000	-	0.667	-	0.667	0.667
Carp	1.333	3.667	5.333	3.333	3.333	4.000
Silver redhorse	0.667	-	0.667	-	0.667	-
Golden redhorse	-	-	0.667	-	-	-
Shorthead redhorse	1.667	0.333	-	-	-	-
Northern river carpsucker	0.667	0.667	11.333	-	1.333	-
Blue sucker	-	0.333	-	-	-	-
Spotted bass	-	0.333	-	-	-	-
Number per kilometer	37.667	27.667	28.000	15.333	14.667	21.333
Kilograms per kilometer	13.094	15.080	22.842	10.654	10.309	18.593
Ave. no. species per collection	3.667	3.667	5.667	2.667	4.000	5.000
S-W Diversity(no.)	0.749	0.830	1.390	0.713	1.277	1.418
Composite Index of Well-being	4.747	4.468	5.340	3.436	4.724	5.412
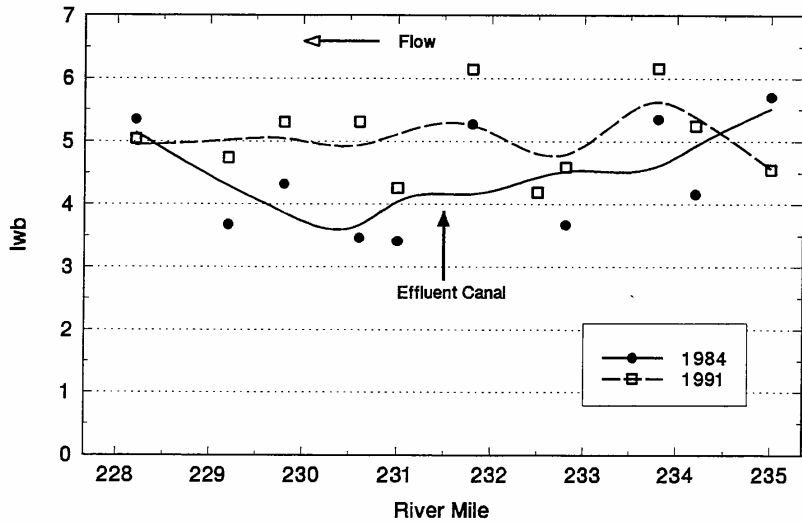
Figure 128: Composite index of well-being (Iwb) profiles derived from electrofishing catches of fish during species studies of 1984 and 1991.

The Effect of the Lafayette\West Lafayette Metropolitan Area

Evaluation of the Lafayette/West Lafayette section of the middle Wabash River is a major challenge because of the close proximity of multiple negative influences, all of which potentially affect water quality to greater or lesser extent. The upriver boundary of this section of river is the US 52 bridge (Rkm 504 = RM 313) and the lower boundary is Ouiatenon (Rkm 493 = RM 305), but the urban influence extends downriver at least as far as Granville Bridge.

In addition to general urban nonpoint-source pollution which periodically and diffusely enters along 10 km (6 miles) of river, there are 4 major point sources (Figure 129). In order from upriver to downriver, they are: 1) the West Lafayette, Indiana Sewage Treatment Plant (STP) effluent, 2) the Lafayette, Indiana STP, 3) the Eli Lilly Tippecanoe Laboratory STP, and 4) Wea Creek. These point sources enter the river at approximately 1.5 to 2.0 km (1 mile) intervals. The Elliot Ditch tributary of Wea Creek, as well as lower Wea Creek, has been a major source of industrial pollutants for decades.

A minimum of five fish collecting stations were established between the US 52 and Granville bridges, including these point sources, since 1977. Figure 129 shows the recent locations of some of these sites. Rather than examine individual years, the data has been grouped into 4 periods of time: 1) 1975-80, 2) 1981-85, 3) 1986-90, 4) 1991-93. Each of these periods includes one low-flow or drought summer (1977, 1983, 1988, and 1991).

The composite index of well-being (Iwb) profile through this section of river is shown in Figure 130. The fish community with the highest Iwb is located immediately downriver from the West Lafayette STP before the effluent thoroughly mixes with river water. The fish communities deteriorate progressively as mixing occurs downriver and as the other effluents are added. During the period 1975-80, the cumulative depression of water quality and the fish community was conveyed well downriver from Ouiatenon. During the last three periods, however, the recovery appeared to be more rapid. The depression was very mild during 1986-90, a period which was characterized by the "best" fish communities throughout the river.

Iwb profiles during drought years of 1977, 1983, 1988, and 1991 indicate a strong initial decline in community quality as the river recieves wastes from Lafayette and West Lafayette (Figure 130). The lowest values were found in the section downriver from Wea Creek and Ouitenon, as they were in the overall data, with a near-recovery by the time the river reached Granville Bridge.

The DCA analysis indicates the same basic pattern of changes through the Lafayette\West Lafayette section of the river (Figure 131). The fish communities of 1975-80 were qualitatively different from those in the other three periods so that the population changes which occurred as the river flowed through Lafayette/West Lafayette area are indicated by open circles and arrows. Major changes take place between Mascouten and the West Lafayette STP, after
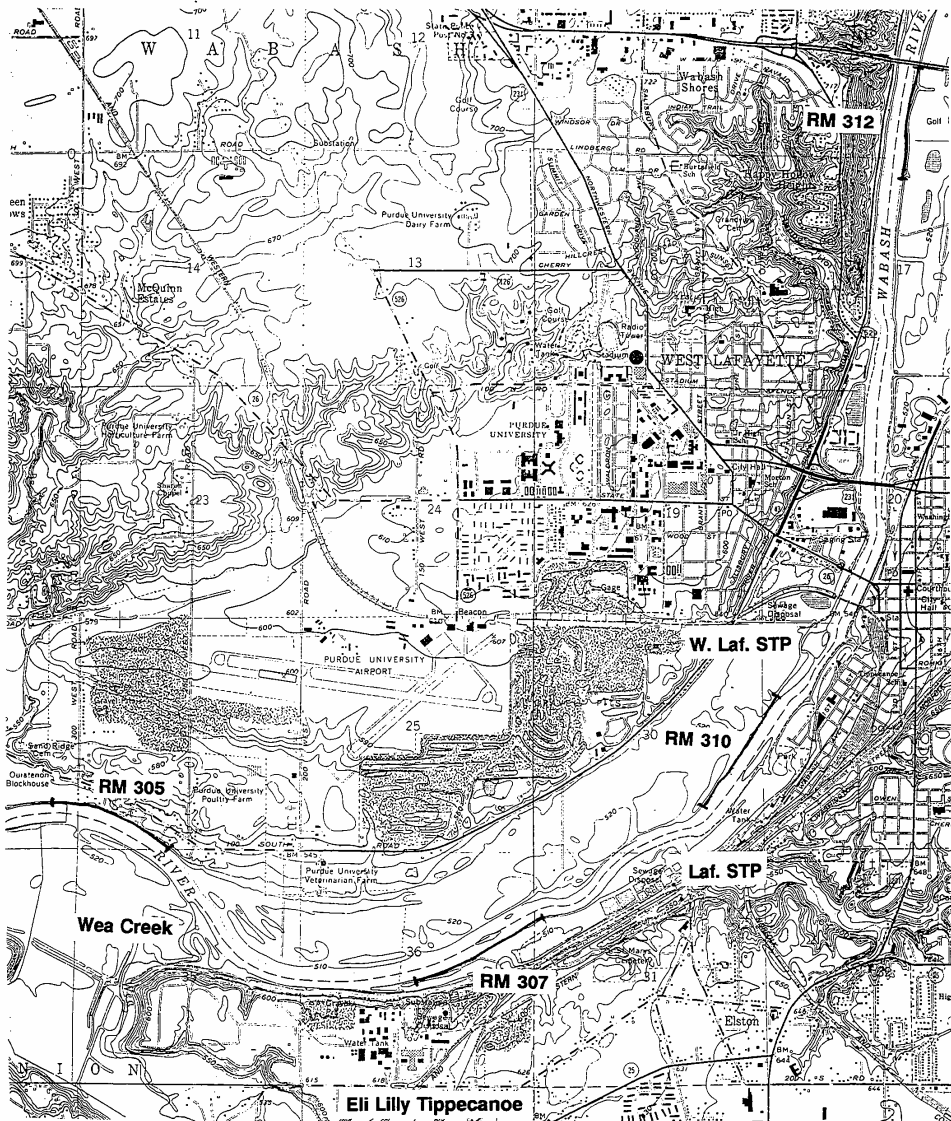
Figure 129: Map of the Lafayette\West Lafayette\Eli Lilly - Tippecanoe Laboratory area showing the location of fish collecting sites.

200
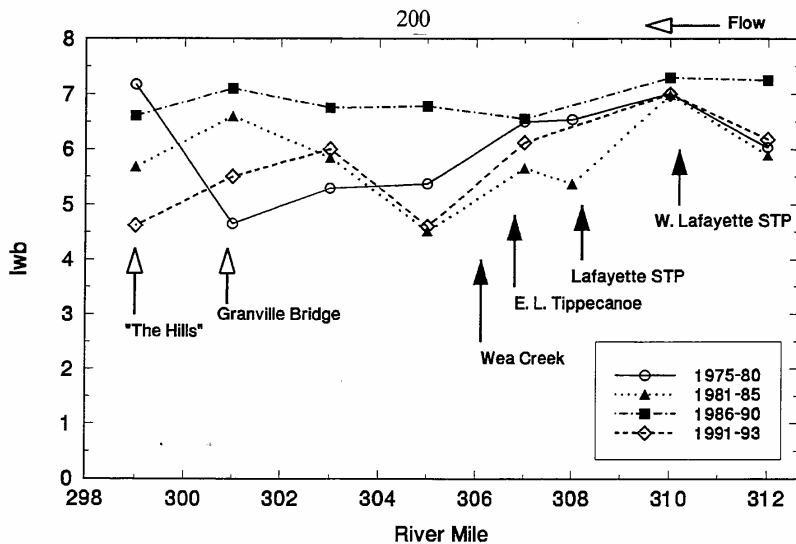
Figure 131: Composite index of well-being (Iwb) profiles for the Wabash River at Lafayette\West Lafayette grouping the data into five year blocks. Each block contains one low-flow summer.
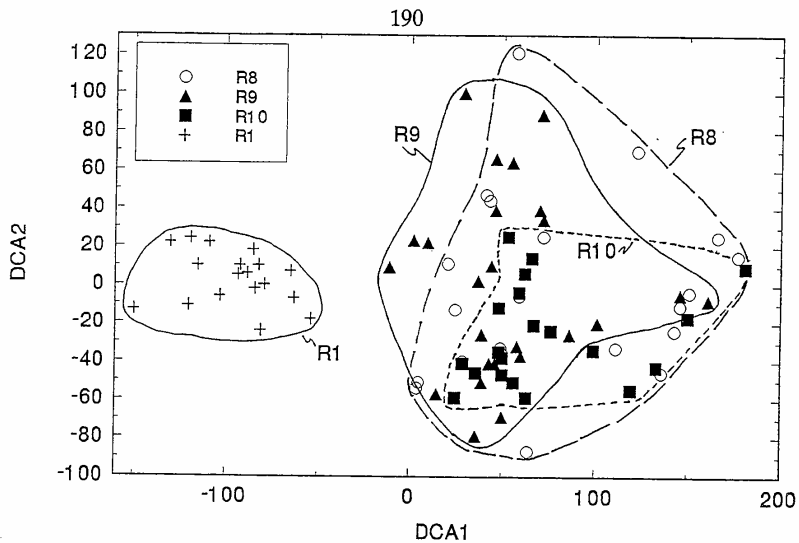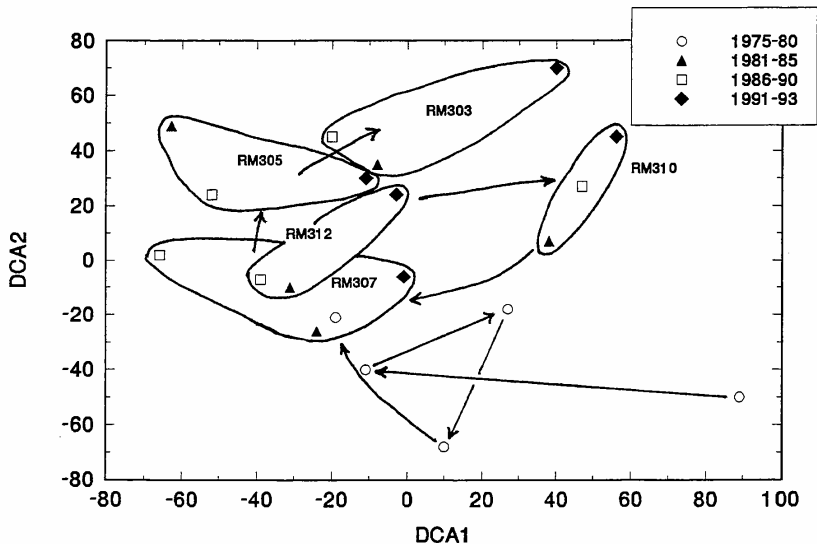

Figure 130: Plots of the first two axes of detrended correspondence analysis (DCA) of species abundance (no/km) for the Wabash River at Lafayette and West Lafayette, Indiana .

which some slight degree of recovery occurs. However, the populations continue to deteriorate downriver from Ouiatenon.

The patterns of population changes which the last three periods exhibit are similar to each other, but differ from the 1975-80 pattern (Figure 131). During 1975-80 the populations were severely altered between Mascouten and the West Lafayette STP, after which they recovered slightly before continuing to change in the region downriver from Wea Creek. After 1980 the populations exhibited a quicker recovery by the time the river reached Granville Bridge.

The various community indices and catch rates of species populations were examined at Mascouten, the Ouiatenon area, and the first two stations downriver from Granville bridge ("The Hills" and Collier Island) combining all of the catches from 1975 through 1993 (Table 17).

All community index values were lower in the Ouiatenon section than in flanking areas. Relative biomass (kg/km) was particularly low, because the age/size of fish residing in the impacted section was lower than in flanking areas for most species.

Goldeye, mooneye, spotted bass, and blue suckers were much less abundant in the Ouiotenon section and the first three species remained scarce downriver from that point. Catch rates of catfish, carp, white bass, silver redhorse, shorthead redhorse, and carp-suckers were depressed at Ouiatenon and then recovered downriver.

Several species of fish were at least as abundant at Ouatenon as they were in flanking areas, including shortnose gar, gizzard shad, drum, golden redhorse, longear sunfish, and smallmouth bass.

It does not appear possible to distinguish individual effluent effects because no effects were instantaneously exerted, with the possible exception of chlorination products. Nor can point-source impacts be separated from the general urban nonpoint-source effects. Rather, it appears that the depression in the fish community between Wea Creek and Granville Bridge is probably the result of the cumulative impact of all of these effluents combined. The negative effects that Lafayette/West Lafayette do exert on the riverine fish community are limited to a relatively short distance after which the direct effects fade.

This is not to say that urban contributions of nutrients do not have some measureable influence further downriver on such biotic components as phytoplankton, for example. This is an aspect that needs to be addressed by future research.

Iwb profiles of low-flow years (1977, 1983, 1988, and 1991) were similar to those of the five-year groupings (Figure 132). The summers of those years were particularly dry with less than normal nonpoint-source pollution from city streets. Therefore, the impacts exhibited probably reflect the sum of point-source pollutants, ie. the STPs at Lafayette, West Lafayette, Eli Lilly's Tippecanoe laboratory, and other industries. The recovery of fish populations is fairly complete by the time the river reaches Granville bridge. The composite index of well-being (Iwb) profiles indicate that the "best" fish populations were usually found immediately downriver from the West Lafayette STP. A similar concentration occurred at the Terre Haute, Indiana STP.

Table 17: Mean community values and species abundance during the period 1975-93 at (a) Mascouten, (b) Ouiotenon, and (c) "The Hills" and Collier Island.

Species\Community Index	Mascouten (RM 312)	Ouiotenon (RM 305)	"Hills" & Collier Is. (RM 301 & 299)
Longnose gar	0.816	0.634	0.821
Shortnose gar	0.327	0.697	0.442
Gizzard shad	15.429	14.388	10.442
Goldeye\Mooneye	3.102	0.845	1.179
Channel catfish	2.490	1.437	2.189
Flathead catfish	0.449	0.592	1.137
White bass	1.510	1.225	1.326
Freshwater drum	1.265	1.310	0.905
Carp	6.735	4.627	6.211
Silver redhorse	1.673	0.697	1.326
Golden redhorse	1.673	1.859	1.642
Shorthead redhorse	2.776	1.416	3.874
Northern river carpsucker	4.735	3.317	3.242
Blue sucker	0.490	0.021	0.379
Longear sunfish	0.531	0.676	0.653
Spotted bass	0.367	0.169	0.168
Smallmouth bass	0.286	0.845	0.253
Sauger	0.857	0.761	0.589
Number per kilometer	49.755	38.381	40.400
Kilograms per kilometer	28.374	18.097	28.194
Ave. no. species/collection	8.306	6.663	7.705
S-W Diversity(no.)	1.623	1.458	1.624
Composite Index of Well-being	6.364	5.729	6.256

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Total Number of catches =    49        95        95
Total km electrofished  =    24.5      47.3      47.5
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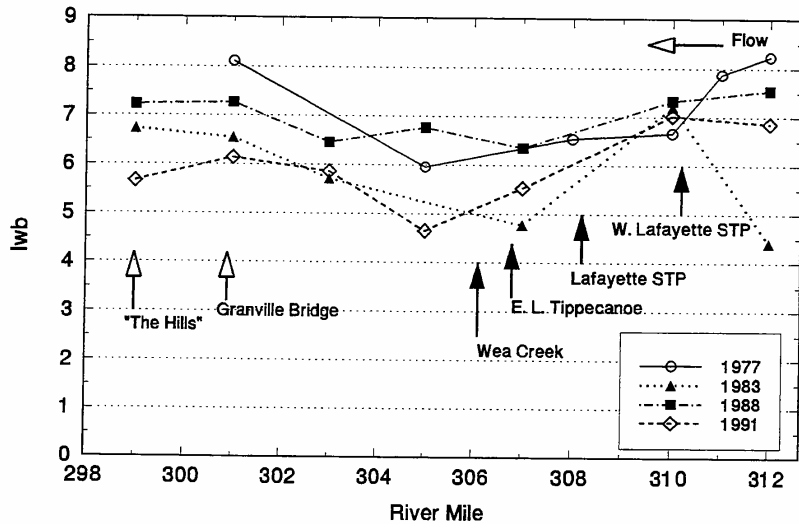
Figure 132: Composite Index of Well-being (Iwb) profiles for the Wabash River
at Lafayette\West Lafayette during low-flow summers of 1977, 1983, 1988, and 1991.

The Terre Haute Metropolitan Area

The Terre Haute area is approximately the same size as the Lafayette/West Lafayette area 160 km (100 miles) upriver. The Wabash River, which forms the western boundary of Terre Haute, has been heated by PSI-Energy's Wabash EGS eight kilometers (5 miles) upriver. Many of the city's manufacturing plants are concentrated on about 3 km (2 miles) of the east shore of the Wabash River on "high ground". Treated domestic wastes from Terre Haute enter the river at about Rkm 330 (RM 205).

Three fish collecting stations are located in the metropolitan area (Figure 133). The most upriver station (RM 211) is situated on the west bank just upstream from the Conrail RR (old N.Y. Central) bridge. It was intended to be an "ambient" station for the Terre Haute area since it is not subject to nonpoint-source runoff from Terre Haute streets and is located as far downriver as possible from the thermal influence of the Wabash EGS. However, catches of fish at this site have been less than satisfactory over the years.

The second site is located immediately adjacent to a vertical sea wall (RM 210). It is not considered to be good habitat and is deeper than desirable at high river levels. Nevertheless, catches of fish at this station have been surprisingly diverse.

The third site is located several kilometers downstream in the southern part of Terre Haute at RM 207. It was originally placed downriver from the I-70 bridge, but it was moved to its present position above the bridge because of increasing water depths and decreasing catches of fish at the old site.

The fourth site in the Terre Haute area is located at about RM 204, a short distance downstream from the Terre Haute STP effluent. It consists of a good gravel bar with relatively shallow, fast water and is regarded as excellent aquatic habitat.

Other downriver stations included in the analysis were RM 203 near the Federal Penitentiary, RM 199 upriver from Honey Creek, RM 197, RM 192, and RM 191. Both of the latter stations are located above Big Creek. Some of these stations are situated quite far apart in most cases, but in the best habitat available. The following analysis groups the data into five-year blocks of time beginning in 1974 when fish were first collected in this area.

The Iwb profiles through this section of river are shown in Figure 134. Bridges, geographical features, and the locations of three larger tributaries are also indicated.

Little Sugar Creek, entering from the west and downriver from the I-70 bridge, entered the Wabash River as an iron-red stream until this decade. It originates in the now rehabilitated Green Valley mine, close to the Indiana-Illinois border. As indicated in the chemical\physical section, this deep coal mine was closed in 1963, but the 100+ acre gob-pile continued to pass acid, heavy metals, and sediment into Little Sugar Creek (Thomas 1978) and the Wabash River until fall of 1994. Honey Creek, which enters the Wabash River at Rkm 320 (RM 198) from the northeast, has a history of pollution from coal strip mines in its headwaters (Whitaker and Wallace 1973).
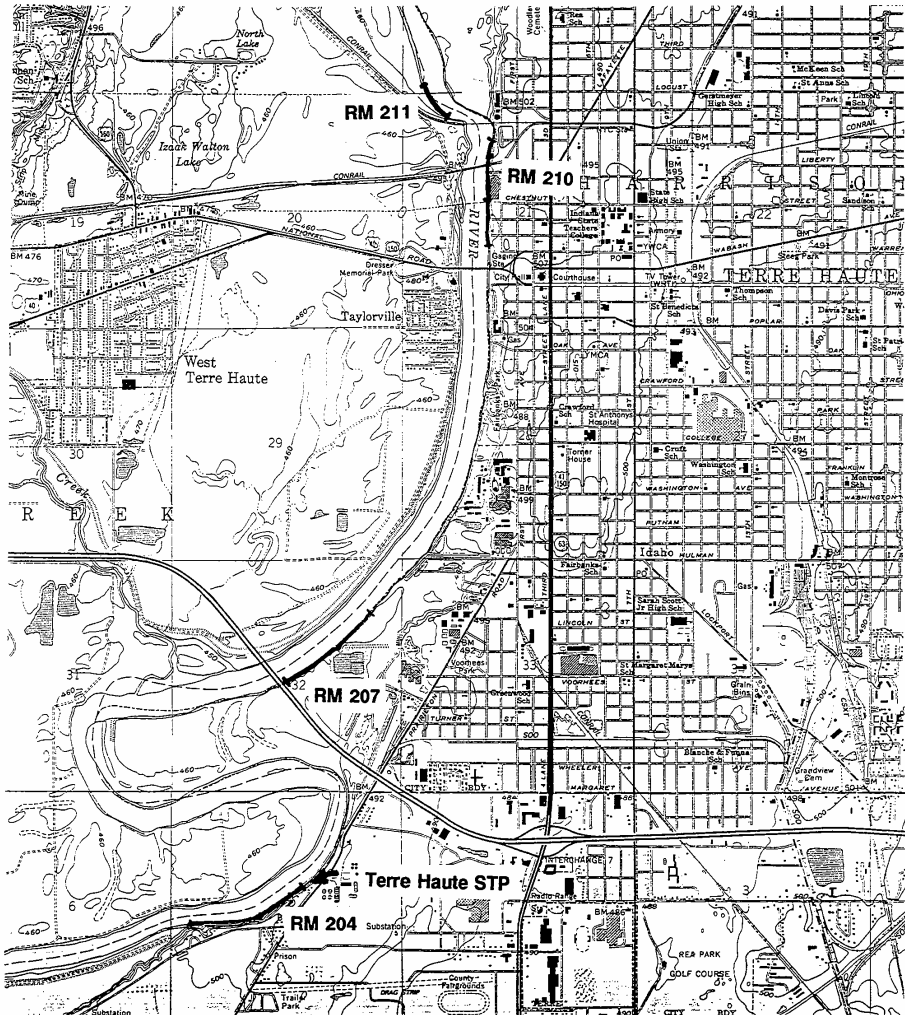
**Figure 133: Location of collecting sites at Terre Haute, Indiana.**
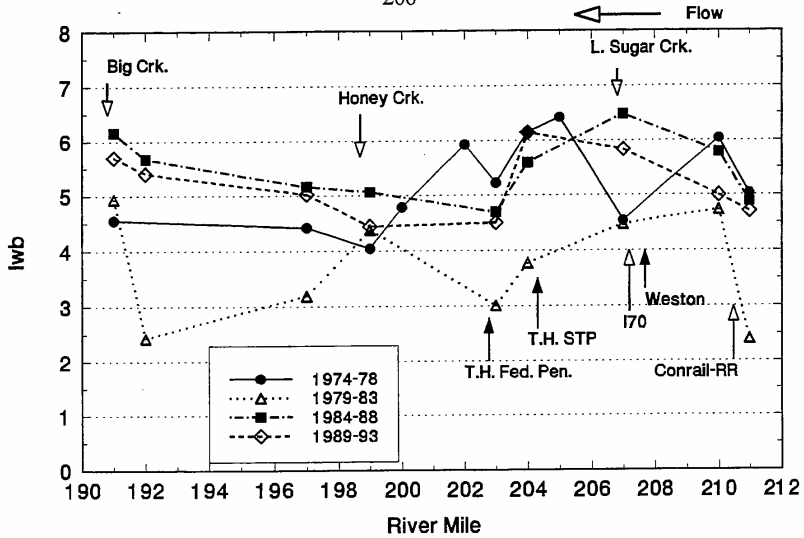
Figure 134: Composite Index of Well-being (Iwb) profiles for the Wabash River at Terre Haute, Indiana grouping the data into five year blocks, each of which includes one low-flow summer.
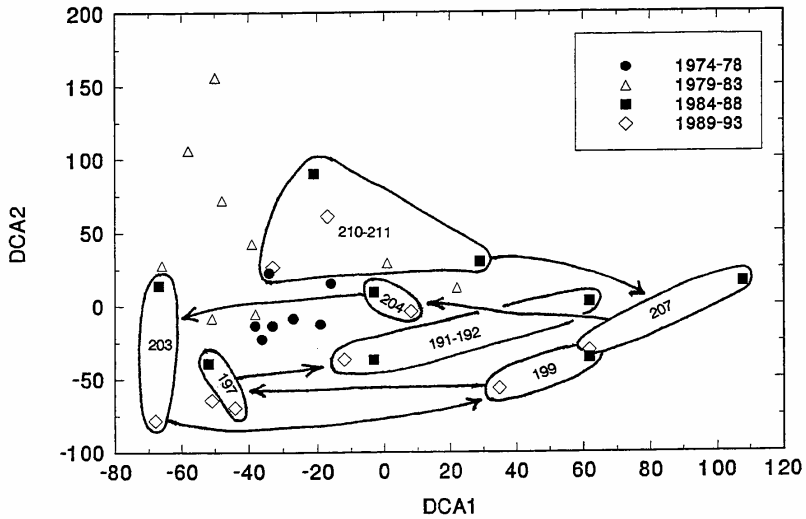
Figure 135: Plots of the first two axes of detrended correspondence analysis (DCA) using species abundance (No/km) at collecting stations in the Terre Haute, Indiana area.

Iwb profiles indicate that the fish community improves as the river flows past the Terre Haute metropolitan area (Figure 134). The best fish community was consistently found between the I-70 bridge and the Terre Haute STP. The community rapidly deteriorates below the Terre Haute STP and finally recovers 21 km (13 miles) downriver near the mouth of Big Creek.

The DCA indicates the relative overall differences in the fish communities at the fish collection sites over time (Figure 135). The spatial trajectory is indicated for the periods 1984-88 and 1989-93. The best fish community was found during 1989-93 at RM 207 and the worst at RM 203. During the period 1979-83 when the Iwb at all sites was depressed there is a clustering of sites at the upper left area.

More specific comparisons were made of the fish communities at three sites for the period 1984-1993: (a) RM 207 upriver from the Terre Haute STP, (b) RM 203 three km (2 miles) downriver from the Terre Haute STP, and (c) RM 191-192 just above Big Creek. As in the Lafayette/West Lafayette area, all of the community values were lower at the most impacted site at RM 203 compared to upriver and downriver sites (Table 18). Biomass was particular low at 10.927 kg/km compared to 32.202 kg/km

above the STP and 20.904 kg/km near Big Creek. The main reason for this was that the average size of many species was also much lower at RM 203 than in flanking collecting sites.

Species populations whose catch rates (no/km) were lower at RM 203 than at flanking areas included gizzard shad, channel catfish, flathead catfish, white bass, freshwater drum, carp, northern river carpsuckers, redhorse, and sauger and walleye.

Iwb profiles of drought years (1977, 1983, 1988, and 1991) were lower relative to the 5-year Iwb profiles (Figure 136) with an even deeper depression downriver from the Terre Haute STP.

The overall impact of the Terre Haute metropolitan area appears to be measureably less after 1983 than before. Furthermore, there appears to be a small, but consistent improvement in the recovery of the fish community downriver from the Terre Haute STP during the period 1989-93 compared to the previous five-year period 1984-88. Nevertheless, the zone of recovery is long, with evidence for negative impacts over a distance of approximately 17 km (11 miles) downriver from the Terre Haute STP.

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Table 18: Mean community values and species abundance during the period 1984-1993 at (a) RM 207, (b) RM 203, and (c) RM 191-192 combined.

Species\Community Index	Above T.H. STP (RM 207)	2 miles below STP (RM 203)	Above Big Creek (RM 191-192)
Shovelnose sturgeon	-	-	0.185
Longnose gar	0.222	1.111	1.926
Shortnose gar	1.259	5.037	4.407
Gizzard shad	26.519	12.593	14.185
Goldeye\Mooneye	0.518	1.211	0.481
Channel catfish	12.444	0.444	5.185
Flathead catfish	4.148	2.370	3.519
White bass	1.556	0.296	0.556
Freshwater drum	3.333	0.074	1.037
Carp	8.074	0.815	5.037
Redhorse species	0.150	-	0.259
No. river carpsucker	4.444	0.222	1.000
Blue sucker	0.074	0.148	0.704
Buffalofish	0.220	0.444	0.444
Centrarchid bass	-	0.074	0.222
Sauger\Walleye	0.520	-	0.111
Number per kilometer	64.593	25.259	40.185
Kilograms per kilometer	32.202	10.927	20.904
Ave. no. species\coll.	6.593	4.074	5.944
S-W Diversity(no.)	1.337	1.090	1.370
Index of Well-being	6.192	4.608	5.753

Total Number of catches =   27   27   54
Total km electrofished =   13.5   13.5   27
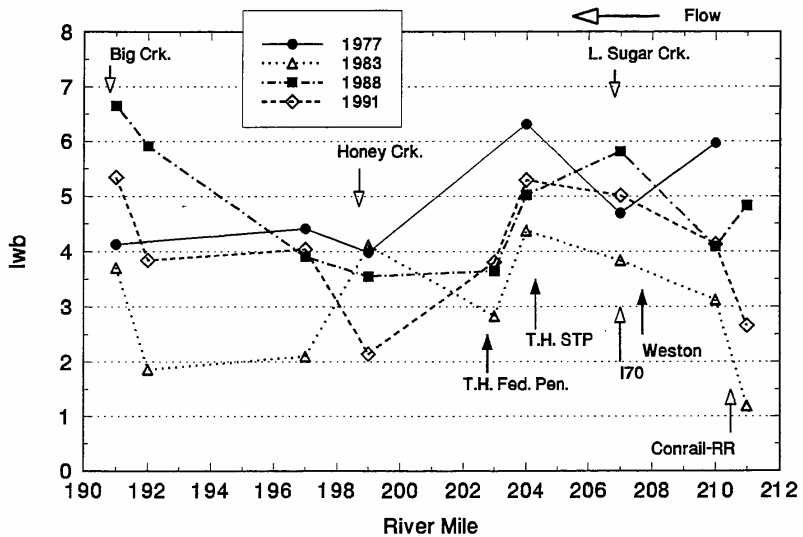
Figure 136: Iwb profiles for the Wabash River at Terre Haute, Indiana
during low-flow summers of 1977, 1983, 1988, and 1991.

Validation of Iwb and DCA Interpretation

The primary criteria for selecting the location of each collecting site was that the habitat include relatively fast current, moderate depths, and gravel bottom. This kind of habitat is most often located on the outside of gradual bends in the river. This type of habitat was found to yield about 50% more individuals and 25% more species than slow-moving, deeper, or midstream locations during 1968-70 at the Cayuga EGS construction site (Gammon 1973). An additional positive factor is that fast-water habitats also tend to be avoided by the ubiquitous and numerous gizzard shad which favor the quieter habitats of backwaters and eddys.

This criterion was developed after sampling a great range of habitat types in the preoperational electrofishing studies during 1968-70 at the Cayuga EGS site. As indicated previously, the eight zones studied at Cayuga EGS included a) the shallow, slow, and sandy inside of the river bend (Zone 1), b) the deep cutbank habitat on the outside of the river bend (Zone 2), c) relatively slow current with moderate depths over a sandy bottom (Zones 4 and 6), d) moderately fast current with shallow water over a sandy bottom (Zone 8), and e) fast current, moderate depths, and a gravel bottom (Zones 3, 5, and 7). Zones 3, 5, and 7 were much more productive when electrofished and served as examples of the type of ideal habitat sought for all of the collecting zones established in 1973 when the "long distance" surveys began.

In the absence of a habitat evaluation methodology for large rivers such as the Wabash, it might be supposed that the depressions in the fish communities down-river from the Lafayette\West Lafayette and Terre Haute metropolitan areas could have

resulted from locating the collecting sites in areas of poor habitat. One of the reasons some collecting sites were located so far from each other was that suitable habitat was simply absent within the intervening segment of river. Nevertheless, the possibility does exist that habitat alone could create the observed Iwb and DCA patterns at Lafayette\West Lafayette, Indiana.

The influence of habitat type on electrofishing catches and the resulting DCA patterns was tested by analyzing two data sets simultaneously: a) the electrofishing catches in eight zones at Cayuga EGS during 1968-70, and b) the electrofishing catches in eight collecting sites in the Lafayette\West Lafayette area (RM 299 to RM 315) during the years 1986-90.

The habitat diversity within the Cayuga EGS Reach is much greater than it is within the collecting sites in the Lafayette\West Lafayette segment. However, the Cayuga EGS zones are distributed over a relative short distance (5.2 km = 3.25 miles) of river while the sites at Lafayette\West Lafayette are distributed over a longer stretch of river. Nevertheless, several collecting sites in the immediate vicinity of Lafayette\West Lafayette (RM 307, 305, and 303) are located close together within a comparable distance.

The results of the DCA are illustrated in Figure 137. The direction of river flow between adjacent collecting sites is indicated by arrows. The fish community at the RM 310 site deviates substantially from those in flanking collecting stations at RM 312 and RM 307. However, even when this is ignored, there is much less similarity among the fish communities at RM 307, 305, 303,

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and 301 than among the fish communities in Zones 1, 3, 5, and 7 at Cayuga. Therefore, it is concluded that the dissimilarities are caused by water quality and not habitat.

This DCA also illustrates the similarities of fish communities between upriver sites RM 315 and RM 312 and downriver sites RM 301 and RM 299 from Lafayette\West Lafayette, indicating that the fish communities have recovered from metropolitan influences by the time the river reaches the "Hills" (RM 301) and Collier Island (RM 299).
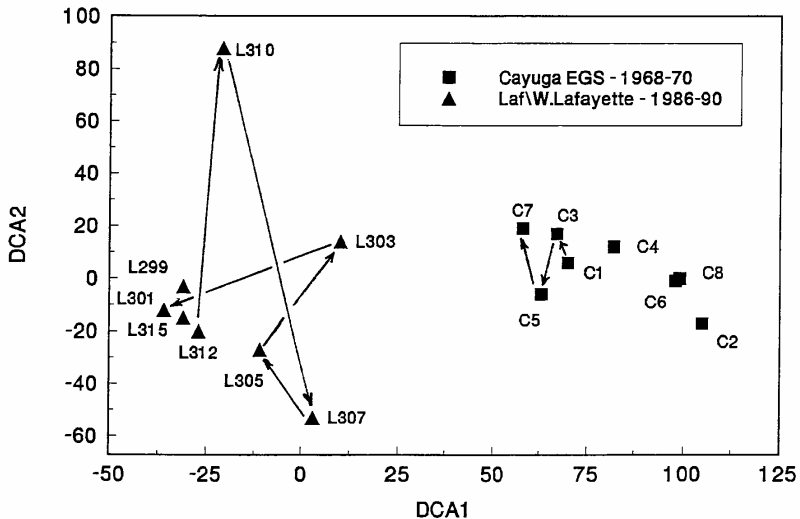
Figure 137: Plots of the first two axes of detrended correspondence analysis (DCA) of species abundance (no/km) at preoperational Cayuga EGS and near Lafayette\West Lafayette, Indiana.

Development of a Large River Index of Biotic Integrity for the Wabash River

Biotic communities have often been used in the past to evaluate environmental conditions, although their complexities through time and space are such that some simplification is almost always necessary. The development of the Iwb discussed in previous sections is an attempt to extrapolate from one important component of the fish community, the larger, longer-lived species, some insight into the environmental quality of different parts of the Wabash River under a variety of conditions imposed by man and nature.

The development of the Index of Biotic Integrity or IBI by Karr (1981) was motivated by the same desire to use the biotic communities of small streams as a measure of overall environmental quality. Karr and his coworkers have proposed, developed, refined, and extended methods for quantitatively determining an Index of Biotic Integrity or IBI for stream ecosystems (Karr 1987; Karr, Fausch, Angermieier, Yant, and Schlosser 1986; Karr, Yant, Fausch, and Schlosser 1987, and Karr 1992).

Originally developed for small streams with a focus on the fish community, this approach has been expanded to include larger, more diverse aquatic systems (Miller and others 1988) and has been broadened to include macroinvertebrate and microbenthic communities as well. The IBI approach has been especially valuable in smaller aquatic ecosystems because sufficient sampling intensity provides a fairly accurate portrait of fish community structure.

Until recently, however, there has been a reluctance to apply the system to larger rivers. Deterrents include (1) the formidable effort which must be exerted to adequately sample all available habitats, (2) the highly variable and unpredictable discharge rates, (3) the considerable differences among the large rivers within any major drainage system, and (4) the fact that most large river ecosystems are disturbed by point-source and nonpoint-source pollution and barge traffic or otherwise altered by damming and/or channel modification.

Recently, Simon (1992) studied the White River system of central Indiana with the purpose of testing the IBI methodology on large river systems. The objectives of the study included: (1) developing biological criteria for **large** (DBA < 2000 mi^2) and **great** (DBA > 2000 mi^2) river reaches of the White River system using the IBI and habitat classification; (2) identifying areas of least disturbance within that river system to serve as comparative reference stations; and (3) developing maximum species richness (MSR) lines from reference stations for each IBI metric based on drainage basin area (DBA).

Additional secondary objectives were to evaluate and assess the impacts of two electric generating stations (EGS) on the West Fork of the White River and two other EGSs downriver from the junction of the East Fork and the West Fork of the White River.

The collecting sites were variable in length. Sites located on smaller river segments were 11-15 stream widths in length, while those located on larger segments were 0.5 to 1.0 km long. Collecting sites were located in segments which were not directly

influenced by tributaries, discharges, or pooled areas.

A T&J pulsed-DC generator with 300 VDC output mounted in a Coleman Sport-canoe served as the electrofishing device. Sites located in smaller river segments were electrofished by wading while deeper sites were floated. Young-of-the-year fish longer than 20 mm were excluded from computations of the IBI, but larger y-o-y were included. Catch per unit effort was calculated as the total number of individuals captured per 15 river channel widths.

Simon (1992) proposed two slightly different sets of metrics for calculating IBI values according to drainage basin area: (1) collecting sites within drainage basin areas (DBA) less than 2,000 mi^2 in extent and (2) sites within drainage basin areas larger than 2,000 mi^2. This division was based on the observation that big river species such as shortnose gar, drum, flathead catfish, skipjack herring, mooneye, and goldeye appeared in the catches only in sites with DBAs greater than 2,000 mi.^{2}.

Thirty-nine of 52 sites were located in river segments larger than 2,000 mi^2 and were designated as sites from **Great Rivers**. All other collecting stations were located where DBAs were less than 2,000 mi^2. Most were designated as sites from **Large Rivers**. However, two of the 52 sites were situated on the upper West Fork and had DBAs less than 100 mi^2 and two additional sites were located on the Driftwood River, a tributary of the West Fork White River.

The middle Wabash River readily falls within the **Great River category** since its DBA varies from 4,072 mi^2 (10,546 km^2) at Delphi, Indiana to 13,112 mi^2 (33,960 km^2) at

Merom, Indiana (Table 19).

It is the intent here to examine this study and its results for possible application to the Wabash River studies. One of the positive attributes of the IBI system is that relatively complete data collected in the past can be reanalyzed for IBI scores and their patterns of change through space and time. Evaluations may then be made regarding the direction and magnitude of the observed differences and whether changes in the physical and chemical environment may have been influential.

Sometimes an existing set of metrics may serve as a valid criteria for studies of another stream system. A more desirable procedure for extensive studies involving many sampling sites is to base the scoring for each metric on the data derived from onsite collections themselves.

The metrics used by Simon (1992) to compute Index of Biotic Integrity values for **Great Rivers** are presented in Table 20. Each metric is based on numbers and their derivatives; number of species collected, number of individuals per unit effort, percent of individuals in the sample which are carnivorous, or percent individuals belonging to sensitive species, etc.

There are several problems to be addressed before the IBI protocol used on the White River can be applied to the Wabash River.

There are several key differences between the White River study and the Wabash River studies which could potentially affect the IBI outcome. One complicating factor is that the collecting protocols used to sample the fish community differ

Table 19: Drainage Basin Area (mi^2) of the Wabash River at different locations along its length (Hoggatt 1975).

Location	DBA mi^2 (km^2)	DBA of Tributaries
Huntington Lake dam	717 (1857)	
Lagro (below Salamonie R.)	1704 (4413)	(Salamonie R.: 560 mi^2)
Wabash, IN	1768 (4579)	-
Peru (below Mississiniwa R.)	2686 (6957)	(Mississinewa: 808 mi^2)
Logansport (above Eel R.)	2964 (7677)	(Eel R.: 774 mi^2)
Delphi, IN	4072 (10546)	
Lafayette, IN	7267 (18822)	(Tippecanoe: 1950 mi^2)
		(Wildcat Crk.: 791 mi^2)
Attica, IN (above B. Pine Crk.)	7682 (19896)	(Big Pine: 327 mi^2)
Cayuga, IN (above B. Verm. R.)	8294 (21481)	(Big Vermil.: 1298 mi^2)
Montezuma, IN (above Sugar Ck.)	10295 (26664)	(Sugar Crk.: 808 mi^2)
Montezuma, IN (above B. Racc.)	11144 (28863)	(Big Raccoon: 520 mi^2)
Clinton, IN	11708 (30324)	
Terre Haute, IN	12265 (31766)	
Darwin, IL (above Prairie Crk.)	12731 (32973)	(Prairie Crk.: 58 mi^2)
Hutsonville, IL	12986 (33634)	
Merom, IN	13112 (33960)	

substantially in the White River and Wabash River studies. The collecting apparatuses used and the ways in which they were operated differ. The boom electrofishing system employed for the Wabash River collections is designed to produce a larger effective electrical field than a hand operated electrode system. It may or may not be more effective at greater depths. It is larger and less mobile and requires greater water depths in which to operate. It is too unwieldy to manually push along by hand in shallow areas and this limits its use in very shallow shoals.

A second critical difference is the criteria used to select collecting sites. As in the White River study, most Wabash River sites were placed distant from the direct effects of tributaries or effluents. However, some sites were located in fast, deep chutes created by gravel near tributary mouths. Most of the Wabash River sites were intentionally located in relatively fast water over gravel bottom on the outside of river bends because we found that larger numbers of many of the larger species of fish were located in that particular kind of habitat. Both deepwater sites and extensive shallows were generally avoided, although both types of habitats were used in the Cayuga EGS area. The selection of this particular kind of habitat meant that other types of habitats were not generally included for sampling although they might be present to a limited extent within the regular 0.5 km length of some sites.

These two important differences in approach lead to significant dissimilarities in the composition of the catches. The Wabash River electrofisher was most effective in collecting larger species of fish and least effective on smaller species such as minnows and darters. The smaller species comprise only 17 of the 41 species listed as **large river** fauna. Only 7 of 25 species listed as highly **tolerant** species are minnows and none are darters. On the other hand the list of **sensitive** species includes 66 species, 47 of which are small species which also predominate in lists of **insectivores** and **lithophilous** spawners. Because of these compositional biases lower IBI scores might be expected for samples of fish collected with the boom electrofisher compared to other methods which were more effective on small species.

There were also differences in sampling frequency between the two methodologies. As generally applied, the sampling effort employed for establishing estimates of the IBI involves sampling specific sites on a single date, although a few reference stations may be visited on multiple occasions. The Wabash River collections involve a smaller electrofishing effort applied on multiple days, usually three dates. On a few occasions a fourth sample was taken, but sometimes only one or two collections per site were possible because of flow conditions. Each electrofishing run attempted to collect at all stations within a 4-5 day period so that a longitudinal "picture" in time could be secured. Combining all runs then provided an average portrait of the fish community during the summer. As indicated in an earlier section, there were occasions when the fish community in some river segments was clearly responding negatively to some environmental factor, eg. in Reach 1 during late June and early July, 1983 and in Reaches 5-9 in mid-July, 1988 (Figure 99). When only a single sample is taken there is a greater probability that any one single sample may not be representative.

Table 20: Metrics used to compute Index of Biotic Integrity values for Great River sites in the White River drainage (after Simon 1992).

		Scoring Classification		
Metric Category	Metric	5	3	1
Species Composition			-	
	Total number of species	>23	16-23	<16
	% Large river taxa	>27%	13-27%	<13%
	Number of sunfish species	> 4	2-4	< 2
	No. round-bodied sucker sp.	> 4	2-4	< 2
	No. sensitive species	> 7	4-7	< 4
	% Tolerant species	<15%	15-30%	>30%
Trophic Composition				
	% Omnivores[1]	<15%	15-30%	>30%
	% Insectivores[1]	>65%	40-65%	<40%
	% Carnivores[1]	Varies with drainage basin area		
Fish Condition				
	Catch per Unit Effort[1]	Varies with drainage basin area		
	% Simple lithophils[1]	Varies with drainage basin area		
	% DELT anomalies[1]	<0.1%	0.1-1.3%	>1.3%

[1] Special scoring procedures are required when less than 100 individual fish are collected.

The use of numbers of individuals in five of the metrics is consistent with the IBI approach used on small streams. It may also be equally useful and appropriate in formulating IBI metrics for large/great rivers However, the use of biomass or weight data should probably be examined for the following reason. The size of fish in small streams ranges from fish weighing 1 gram or so to larger fish which weigh 1,000 grams. Small fish are also found throughout great rivers, but so are much larger fish weighing 10,000 grams and more. In using numerical data one emerald shiner weighing a few grams is equivalent in importance to one blue sucker which tips the scale at 6,000 grams. At the same time, the probability of capturing one of the numerous emerald shiners is far greater than the probability of catching a blue sucker.

The inclusion of larger young-of-the-year fish in the IBI determinations in the White River study also presents problems. Presence of these young members is valuable because it provides clues to spawning success of a species. However, the large numbers which sometimes appear after mid-August could easily "swamp" the IBI system. Additionally, it impairs its broad utility for determining IBI values using data from past studies conducted in early summer when y-o-y were totally absent from the catches and future studies which would have to be restricted to late summer and fall in order to maintain comparability. It would be desirable to reanalyze the White River data after y-o-y have been removed.

Time and space prohibits an extensive evaluation of the appropriateness of the IBI protocol suggested by Simon (1992) for the Wabash River samples or its modification. The computer data base of

past catches of fish will have to be extensively revised and new analytic programs written before a thorough analysis can be made.

Initially, however, some selected sets of data have been examined. One of the best available data sets is that of 1977 when DePauw University, Purdue University (Dr. Anne Spacie), and Eli Lilly Company personnel (Dr. Jerry Hamelink) cooperatively electrofished and seined at multiple sites from Delphi to Merom. A preliminary examination of electrofishing data from collecting sites located between the Cayuga EGS and Delphi, Indiana indicates that some metrics may serve for data from both river studies. However, other metrics appear to be unsuitable without further modification.

The data for **Big River** species, for example, indicates a good correspondence from both the White and Wabash Rivers (Figure 137). This figure also includes a limited data set taken from the Wabash River with a boat-mounted battery electro-fisher near Logansport, Indiana in 1978. Big river species appear when the DBAs of both rivers are 2,000 mi^2 and increase to a plateau when the river DBA approaches 5,000 mi^2.

Note that data from the Wabash River collecting stations located between the Tippecanoe River and the Big Vermilion River falls nicely in the DBA gap present in the White River data. That gap is the result of the befurcated shape of the White River basin the drainage basin area suddenly doubles when the East and West Forks join to form the lower White River. Changes in DBA for Wabash River stations are more gradual because of the linear shape of the Wabash River basin.

It would be desirable to modify the proposed Great River IBI system based on data sets from both the White River and the Wabash River. The species included in lists for specific metrics should be reexamined for their appropriateness. Some species which are not currently listed appear to have attributes which would qualify them to be included. Northern river carpsucker (*Carpiodes carpio*) should be included as a Big River species, for example.

If such a broadly applicable system could be structured then it could be tested further with data from other river systems. Both the 1986 and 1987 Wabash River data must also be included in any analysis because the "best" fish communities ever found in the Wabash River flourished at this time. There are also several other White River studies which should be examined.
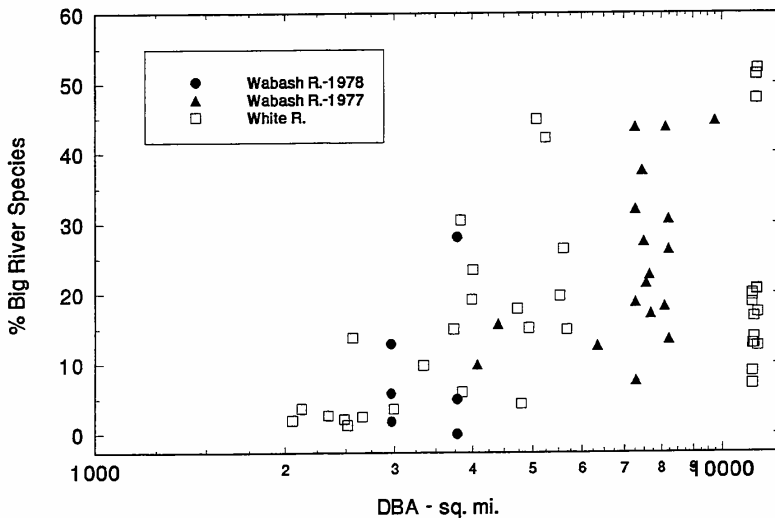
Figure 138: **Percent individuals of big river species relative to drainage basin area.**

DISCUSSION

Most rivers and streams in Indiana are negatively affected by human activities. Nevertheless, some riverine fish communities are surprisingly diverse and healthy, even in waters which appear to be less than optimum. Most of the fish species still live today in the Wabash River just as they did 175 years ago when Rafinesque (1820) and LeSueur studied them. However, the lake sturgeon (*Acipenser fulvescens*), muskellunge (*Esox masquinongy ohiensis*), and stargazing darter (*Percina uranidea*) have disappeared; the northern pike (*Esox lucius*) is rare; and the walleye pike (*Stizostedion vitreum*) persists only because tributary reservoirs are stocked. However, increased collecting activities in recent years have disclosed remnant populations of some species previously thought to have been extirpated.

The initial decline in the river environment was the consequence of a rapidly increasing human population which cleared native vegetation from the land and converted it to agriculture. Excess agricultural production ultimately required navigable waters and the state of Indiana constructed canals for nearly four decades beginning at Fort Wayne in 1828. The canals were finally abandoned in the mid-1860's because of high upkeep expenses, gross mismanagement, and growing competition from railroads.

Despite the extensive changes in landscape and new industrial impacts in the 1880's, Jordan (1890) found the **"fish fauna of the Lower Wabash . . to be unexpectedly rich,. ."** especially in the abundance and number of species of darters at the five sites he visited. However, increased populations and expanding industrial activities soon led to gross organic pollution and adverse human health effects (Craven 1912).

Following four decades of neglect, Gerking (1945) systematically collected fish throughout Indiana, including 16 sites on the Wabash River. He found fewer species of darters at sites sampled by Jordan which he attributed to increased siltation from soil erosion as well as the influence of **"city sewage, cannery waste, coal mine drainage, paper mill waste, and dairy-products factory waste."**

The Wabash River continued to be ignored for two more decades after Gerking's benchmark study. Many of the state's reservoirs were constructed during this period. They served not only to reduce the incidence of downstream flooding, but also to provide waterbased recreational opportunities such as boating, swimming, and fishing as well as real estate development.

The Wabash River is too small and its flow too unreliable to serve as an important transportation corridor. Nevertheless, the Army Corps of Engineers has been prevailed upon to assess its potential in this regard nearly every decade. Neither is there sufficient recreational boating and fishing activity to support much marina development along its length.

The murky, aesthetically displeasing appearance of the Wabash River almost certainly inhibited its recreational useage in the past and continues to do so at the present time. This disturbing quality and the problem of difficult access for boats have probably limited its use by anglers as well as the scientific community. Nevertheless, the

Wabash River, measuring more than 40 square miles in surface area, constitutes the largest body of water contained within the state. Only the Lake Michigan portion of Indiana is larger. As such, the Wabash River represents an underused resource of great potential value, especially since over 10% of Indiana's population lives within easy reach of the river. That aspect alone should generate much more interest on the part of the public and governmental units.

Perhaps the view of the Wabash River as an overlooked, but potentially valuable asset is overly optimistic. Indeed, until the last decade there was little reason for optimism. As a newcomer to Indiana 30+ years ago, I regularly drove over this "dirty" river on my way to Wisconsin. The contrasts of the Wabash River to the Chippewa, Flambeau, and Namekagon Rivers of northern Wisconsin were hardly flattering. However, I found that superficial appearances were deceptive and that a rich and abundant aquatic life actually thrived in the Wabash River. In 1965 Bob Poppe and I spent an eventful October afternoon collecting fish near Montezuma, Indiana with a hastily constructed electrofishing apparatus. Beneath the clouded surface an astounding abundance and diversity of fishes lived and apparently flourished. From that time to the present the Wabash River has grudgingly yielded its mysteries.

The fish community of the Wabash River mainstem has been monitored annually since 1967 , but not until 1984 did the fish community conspicuously improve, perhaps for the very first time since Indiana was settled. Significant population increases for most species followed during the next few years. Before 1984 only a few sport fish were found in the electrofishing catches and the catch rate averaged slightly more than two game-fish per kilometer. The average catch rate quadrupled after 1983 as most sport fish populations enlarged. Even smallmouth bass became abundant in parts of the upper Wabash River. During this entire period of study commercial and sport fishing pressure remained relatively light and did not appear to change much over the period of study.

The sudden and substantial population growth led some fishes to extend their range into areas of the river in which they previously did not or could not live. The density of carp, however, remained unchanged and the gizzard shad population actually declined, probably because of increased predator pressure on young-of-the-year. The average size of many species increased, perhaps because of greater longevity, perhaps due to faster growth, or perhaps because of a combination of both factors.

What elements in the river environment were altered to have kindled this positive reorganization? An examination of changes in key chemical constituents of the river provide few clues. The improvement probably was the result of a combination of events including a gradual, but substantial (50%) reduction in BOD loading to the river because of cumulative improvements point-source waste treatment in conjunction with other events.

The multivariate statistical analysis of catch data and spatial and temporal patterns of the Composite Index of Well-being (Iwb) both indicate that negative local impacts have decreased during the past 10 years at Terre Haute, Indiana. Conditions have also improved during the past 15 years at Lafayette\West Lafayette, Indiana. Furthermore,

it is likely that positive local improvements have occurred at population centers throughout the Wabash River basin because of upgraded treatment of human and industrial wastes. It was also demonstrated that negative thermal impacts were reduced at the Cayuga Electric Generating Station by a relatively small change in operational procedures.

There is no doubt that the concentration of dissolved oxygen (DO) in water profoundly affects aquatic life, especially the fauna, and it appears that a positive change in dissolved oxygen may have played a role in the faunal improvement. The dissolved oxygen model proposed for the middle Wabash River by HydroQual (1984) provides some insights into the basic problem.

The amount of living and dead organic matter in the river (biological oxygen demand or BOD) strongly influences the oxygen status of the river. The greater the amount of BOD, the greater the removal of dissolved oxygen from the water. More oxygen is consumed by in-river processes than is generated by photosynthesis on the average during the summer in the Wabash River and a dissolved oxygen deficit or DOD is the result.

When the Wabash River is at low, stable summer flow the HydroQual model projected DOD values of 2.0 to 2.5 mg/l from Delphi to Montezuma and then sharply increased values of about 4.0 mg/l from Terre Haute to Merom. During the summer months, then, the DO concentration is two to four milligrams per liter less than the river could hold at saturation. This is the opposite spatial pattern exhibited by the Iwb profile and suggests an inverse relationship between the two.

Furthermore, HydroQual estimated that phytoplankton respiration was the largest single user of DO and was responsible for an estimated 50-60% of the DOD in the upper reaches and about 70% downriver from Terre Haute, Indiana.

BOD entering from multiple point sources along the river was the second largest user of oxygen. By far the largest proportion of BOD entering the middle Wabash River, 61% to 77%, was estimated to originate from nonpoint, agricultural sources.

Decomposing BOD accounted for about 10% of the DOD in the upper reaches and over 15% downriver from Terre Haute. Sediment oxygen demand or SOD, which is the removal of oxygen because of decomposition of organic materials in the bottom sediments, was estimated to be the third largest oxygen user. Other oxygen utilizing processes such as respirational uptake by fish and benthos contributed only to a minor extent.

Most of the BOD in the Wabash River consists of decomposable organic matter and phytoplankton. Although the average annual BOD concentration has declined significantly, monthly average levels are as high as ever from July through September because of high densities of phytoplankton. During this period phytoplankton density increases gradually in the upper Wabash River as it flows southward. The highest algal densities occur between Layayette and Terre Haute, Indiana and then remain fairly constant downriver from the latter location.

The low-flow summers of 1983, 1988, and 1991 produced good reproduction and survival of young fish through the first year of

life. Perhaps coincidently there was a 25% reduction in agricultural loadings to the river in 1983 during the Payment-in-Kind (PIK) program when farmers were paid not to grow corn and soybeans. From 1985 through 1992 river discharge during the summer was less than average. Less rainfall presumably resulted in less than usual nonpoint-source pollution. The relative importance of these various contributing factors have not been assessed.

Continued improvement of the Wabash River may depend partly upon limiting the delivery of nutrients to the Wabash River, thereby reducing densities of algae. The resulting effect should be an improvement in the dissolved oxygen and dissolved oxygen deficit balance. Less algae would also result in less turbidity of the water which would be beneficial to sight-feeding game-fish. If algal densities during the summer could be diminished noticably the river's aesthetic qualities would also be enhanced.

Although agriculture occupies a majority of the Wabash River basin, it is not the only nonpoint-source contributor. Active and derelict mines, both old deep mines and old surface mines, may play a significant negative role in their impact on the river ecosystem. It may be just a coincidence that the best fish communities in the middle Wabash River lie upriver from the northern border of coal mines and that their quality sharply declines in the Covington\Perrysville area (Reach 5). Likewise, the stretch of river from Clinton to Terre Haute, Indiana (Reach 8) appeared to be unusually depressed in past years. Perhaps the increase in quality here since 1983 is also linked to less nonpoint-source runoff from mining areas as well as agricultural fields.

There are other elements in the Wabash River basin which contribute to an overall understanding of the ecosystem and its problems. Surveys of the status of the river's riparian corridor was undertaken in 1983 and 1994 because of accelerated cutting of trees and enlargement of fields in many stretches of the river during the 1970s. The extent of eroding banks in 1993 was on the order of 5-7% of the river length overall. Another 5-7% of the river corridor has only one or two trees separating the bank from tilled fields. These figures are lower than those estimated in 1983 perhaps because of the natural establishment of willow groves in the interim.

The riparian status of tributaries such as the lower 12 miles of Sugar Creek together with its extreme upper section and upper Big Raccoon Creek is even less encouraging. Clearly, there is an urgent need to maintain and, in many areas, reestablish an effective riparian buffer along our rivers and streams. Riparian forests are critically important to maintaining a healthy river ecosystem.

Agricultural practices as a whole are of paramount importance when agriculture dominates river basins as they do throughout the midwest. An agricultural revolution of sorts has been underway since about 1990, a revolution which has the potential to benefit our aquatic ecosystems. Conservation tillage practices such as chisel plowing, ridge-till, and no-till have rapidly been adopted throughout the U.S., but particularly in the cornbelt states. All types of conservation tillage reduce soil erosion by minimizing physical disturbance of the soil and maintaining a protective surface coating of crop residue. The adoption of no-till farming, in particular, may prove to be an

important element in improving our river ecosystems because it reduces soil erosion. No-till practices have spread rapidly since 1990 when only 7.5% of corn and soybean fields were grown under no-till practices in Putnam County. By 1993 no-till farming was practiced on 50% of the corn and soybean fields and this increased to 60% in 1994. The continued growth should reduce soil erosion in the future, thereby leading to a reduction in sediment and phosphate pollution. It may possibly even have some reducing influence on nitrate levels since the practice fosters a return of earthworms and other soil organisms to previously plowed fields.

Evaluations of the separate and collective negative impacts due to man must be conducted within changeable and sometimes damaging natural processes such as droughts and floods. Population reactions to the droughts of 1988 and 1991 were not the same. In 1991 populations everywhere were depressed. In 1988 populations were depressed only in the lower eight Reaches. We have no clues as to what might have caused these differences.

In 1992 and 1993 a "new" climatic phenomenon introduced itself into the population dynamics equations - prolonged periods of high water during late summer. High discharge often occurs in early summer, eg. 1968, 1973-74, 1980-82, 1984, 1986, and 1989. However, high discharge for several weeks duration during mid-summer only occurred during 1992 and 1993. The impact on most larger species of resident Wabash River fishes was devastating. Not only was there a direct negative effect on most species populations, but also there was virtually no reproductive success. Populations of larger species in the Wabash River were at their lowest ebb in 1994. It remains to be seen if their recovery will be as swift as it was after 1983.

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